AD-A172 915 TACTILE STIMULATION AS A SUBSTITUTE FOR VISION FOR THE BLIND(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F D KIRSCHNER 1986 AFIT/CI/NR-86-180D 1/2

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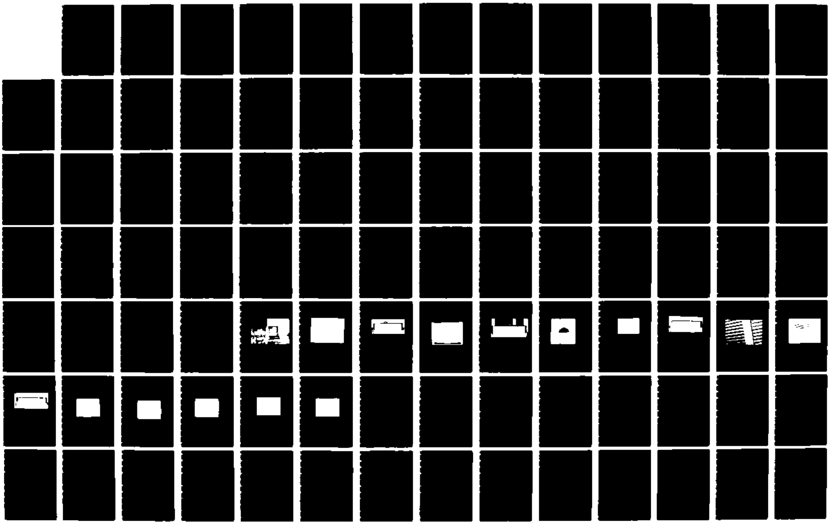

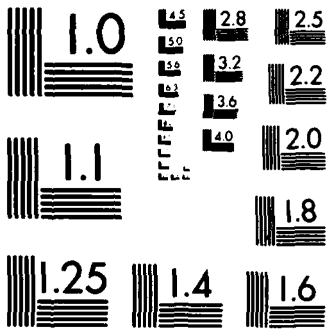
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/CI/NR 86-180D	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Tactile Stimulation As A Substitute For Vision For The Blind		5. TYPE OF REPORT & PERIOD COVERED ~~THESIS~~/DISSERTATION
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Frank Dana Kirschner		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFIT STUDENT AT: The Ohio State University		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 1986
		13. NUMBER OF PAGES 92
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASS
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE: IAW AFR 190-1

Lynn Wolaver 25 Sept 86
LYNN E. WOLAVER
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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TACTILE STIMULATION AS A SUBSTITUTE FOR VISION FOR THE BLIND

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Frank Dana Kirschner, B.S., M.S.

* * * * *

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1986

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To My Wife,

Who Taught me to See

With New Eyes

ACKNOWLEDGMENTS

I wish to thank Professor Herman R. Weed for his advice and support during this research; Dr. Leo E. Lipetz for his invaluable ideas and suggestions and his seemingly inexhaustible patience; Mark. A. Kovach for his work on the stimulator used in this work; Enrico Nunziata for his assistance in programming; Perry Ho for his help in construction of a prototype; and my wife for her professional art work on the figures used in this document, aid in soldering components, and her undying patience and understanding throughout this program. I also wish to thank the Blind Guild of Canton, Ohio, for their support of this project, and the United States Air Force for their funding of my education.

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"Passive Detection of Motion Transverse to the Optical Viewing Axis", IEEE Transactions on Instrumentation and Measurements, Vol. IM-24, No. 3, pp. 248-255, September 1975. Coauthors: Kowel, S.T., Kornreich, P.G., & Lewis, O.

"Applications of Microprocessors", Proceedings of the National Aerospace and Electronics Conference, Dayton, Ohio, May 1978. Coauthor: Borky, J.M.

"The Integer BASIC Token System in the Apple II", Micro, May 1979, Vol. II, No. 12.

"Converting AppleWriter Files", Call -A.P.P.L.E.,Feb. 1982, Vol. 5, No. 2.

"Tactile Vision Substitution", ACEMB, 1985.

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Minor Fields: Communications - Professor Davis, Professor Garber, Professor Ksienski
Digital Systems - Professor Klein, Professor Breeding
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CHAPTER I

INTRODUCTION

Objective of the research

The objective of this research is, on the basis of a first appraisal of the parameters and their ranges for the optimal transfer of video information via the human tactile sensory system, to design, build, and test a system which would allow determining the relative importance and sensitivity of these parameters.

General Concept of Transfer of Information via the Tactile System

The senses of an organism can be viewed as channels through which the organism gains data about its environment. Like any other information acquisition and processing system, each of the senses has transducers, transmission channels, and a processing system. In the tactile sensory system, the transducers (the electro-chemical interfaces between the environment and the system) consist of receptor cells or the endings of afferent nerves and their surrounding tissue. The transmission channel consists of the afferent neuronal connection between the transducers and the processor. The processor consists of that portion of the central

nervous system and related structures which receive the signal. The limitations of the tactile sensory system include the limited dynamic range of the sensors, adaptation by the sensors, the limited effective bandwidth of the transmission channel, and the processing capabilities of the processor. The latter include its speed, its overall data-handling capacity, and its ability to integrate inputs from several different senses. The limitations also include tendencies for these parameters to be affected by the operation of other portions of the nervous system.

When any one system for information-gathering fails, the organism usually makes increasing use of the still-available senses in order to minimize the loss of its incoming information. The tactile senses and the sense of hearing are the primary senses upon which blind people rely for information about their environment. The tactile system is particularly well adapted to serve as a substitute. It has the inherent capability to deal with two-dimensional information because it maps, point by point, tactile sensors in the skin to the somatosensory neurons in the precentral gyrus of the brain [1]. The sensors in the skin which detect tactile stimuli are connected to the brain in such a way that the location of the stimulus on the body is usually perceptible. This ability is made apparent in the children's pasttime of "writing" on one another's back with the finger. The shape of the letters

written is more or less apparent to the child acting as "reader". It is this ability which is to be exploited in the use of the tactile system for video information input. The plan is to use technical means to gather data about the environment, process it in some predetermined fashion, and present it to the tactile system of a blind individual using a vibratory tactile array (henceforth referred to as VTA).

Several physical means are available to gather data about the environment. Acoustical reflections (such as SONAR), electromagnetic reflections (such as RADAR), and light reflections, are the most obvious ones. For this work, the reflection of ambient light (video) was selected because it most closely approximates data provided by normal vision, and because it does not require emission of energy into the environment.

In exploring the use of the tactile system as a channel for data input, we must ask three fundamental questions:

1. How much data can be transferred through the tactile system?
2. How much information is needed for specific tasks which would be of use to the blind, such as navigation in an unfamiliar environment, or locating and picking up objects?
3. What parameters of the vibratory tactile system and what form of signals and patterns presented to it are important in enabling the wearer of a VTA to obtain information about the environment from the data presented through the VTA?

The system which was designed and built as part of this research and is described in this document is essentially a test apparatus which will facilitate investigation of these questions.

History of Tactile Stimulation for Information Transfer

The use of the vibratory tactile system as a substitute for vision is not new. Dr. Paul Bach-y-Rita, University of Wisconsin, reports that a Polish group attempted this in 1898. In 1960, Geldard [2] suggested the use of the skin as a channel for communication. In 1967, Bach-y-Rita [3] demonstrated a tactile vibratory display in the laboratory. Additional experiments were done by others ([4], [5], and [6]), but limited success was reported. The amount of information the wearer received was too low to be of use as a peripatetic aid for the blind; however, when used as an acoustical aid for the deaf, slightly better results were obtained [7].

In the above studies, a very limited range of input signals was explored. Stimulation was done with correlated vibrations, that is, adjacent sites on the skin were stimulated simultaneously with, at most, a reversal of vibration phase of the stimulating signal between adjacent rows of sites. Variations in duty cycle (the ratio of the duration of the active or energy transferring portion of the stimulus to the total period of the stimulus signal) were not

tested; all previous VTAs used a 50% duty cycle. When the system was used as a substitute for vision, no special processing of images, such as edge enhancement, was used. These parameters must be explored, and the relative importance of each and the ranges over which they are effective must be determined if the concept is to prove feasible.

Contents of the Remainder of this Document

Chapter II covers the constraints on the test system, that is, the physiological and electrical parameters believed to be important for information transfer via a VTA, and the ranges over which testing is deemed necessary. Chapter III covers the rationale for the selected design and describes how the design of each element of the system was determined by the system constraints. Chapter IV covers the results upon operation of the test system, providing data to show to what extent each system constraint was met, and giving the ranges of each controllable parameter. Chapter V covers conclusions and suggested improvements of the test system. Appendix 1 gives circuit details to allow modification and repair of the system.

CHAPTER II

SYSTEM CONSTRAINTS

Introduction

In order to design and construct this test apparatus to facilitate exploration of the parameters which have a significant role in transfer of video information via the tactile system, the parameters had to be identified, and the ranges over which they were to be tested had to be specified. For some of the parameters, such as frequency of vibratory stimulation for maximum sensitivity, considerable study had already been done by other researchers ([2] through [8]). For other parameters, however, such as the length of time a particular stimulus pattern should be presented before it is changed, there is little or nothing in the current literature in the field. In selecting the parameters which would be controllable by this system and their associated ranges, we relied, where possible, on data from the literature. For parameters less well documented, our initial experiments using a manually controlled method of activating the VTA were helpful. For yet other parameters for which there was insufficient data, we had to rely on intuitive judgments.

This chapter first briefly defines the parameters which constrained the design of the test system. It then details the methods used to determine the range over which the test apparatus

would be required to control each parameter. Table 1, Significant Parameters, lists the parameters which were considered in this research.

Brief Description of the Parameters Involved

Method of stimulation. The method of physically stimulating the skin's tactile system had already been selected at the beginning of my research. A brief description is given here, since it defines the system which must be built to drive it. For a more complete discussion, see [9].

The skin sensors are sensitive to electrical current, pressure, heat, and vibration. Electrical currents passed directly through the skin were ruled out as the method of stimulation for the following reasons. First, blind persons expressed reluctance to use a device that sent electric currents, however minute, through the wearer. Second, the difference in current density levels between the threshold of perception and threshold of pain is slight, so inadvertent reduction in the contact area between an electrode and the skin could readily result in painful current densities.

Pressure transducers were considered unsuitable because they would have to be bulky, since considerable deformation of the skin would be required. In addition, the pressure sensors in the skin adapt quickly to pressure; that is, they respond to the initial

Table 1 - Significant Parameters

Parameter	How Controlled
Amount of skin deformation	Programmable - depends on transducer current
Frequency of vibratory stimulation	Electronically adjustable
Spacing between stimulated sites	Minimum fixed by VTA
Duration of stimulus	Programmable
Adaptation and recovery times	Fixed, but may vary among individuals
Number of levels	Maximum is fixed by hardware, fewer can be used under program control
Temporal correlation between stimuli	Uncorrelated - fixed
Current range required	Fixed - 0 to 25 mA peak
Impedance of transducers	Fixed
Size of transducers in VTA	Fixed
Number of transducers	Fixed
Power consumption	Fixed
Maximum ratings	Fixed
Effect of loading	Fixed

application of pressure, but their response rapidly decreases if the pressure is held constant [1].

Heat stimuli are not suitable because the skin sensors respond slowly to heat, and spatial discrimination is poor.

Vibration sensors in the skin exhibit less of these limitations, and were therefore selected.

Parameters which depend on the physiology of the tactile (vibration-sensing) system.

Amount of skin deformation required for a perceptible stimulus. For the vibratory tactile system the threshold stimulus is the minimum amount of deformation of the skin which will be reliably perceived. The literature gives threshold values only for stimulation of one point on the skin; there is no information available on threshold when multiple points are stimulated. Stimulation of one site on the skin raises the threshold of surrounding sites, making them less sensitive [1]. This effect is called lateral, or surround, inhibition. It probably affects the stimulus threshold when adjacent multiple locations are being stimulated. This affects the spacing between stimulators and the total number of stimulators which can be employed. Since the VTA used in this research had already been designed and built before this research began, both the spacing and the total number of stimulators were fixed [9].

<u>Frequency of stimulation for maximum sensitivity.</u> The vibration sensitivity of the skin varies with the frequency of the stimulus. This depends on a number of factors. Among these factors are the mechanical characteristics of the skin (its mass, springiness, and viscous damping), and the frequency responses of the vibration sensors and their associated neural circuits.

<u>Spacing between sites.</u> There are no comprehensive data available on the effect of spacing of stimulation sites on the skin on information transfer via the vibratory tactile system. It is clear, however, that using more sites with closer spacing increases the available resolution, up to the point at which the tactile system can no longer distinguish the adjacent sites as separate.

<u>Required duration of stimulation.</u> This refers to the minimum time during which a particular pattern presented by the VTA must remain unchanged. There is no information on this in the literature. Intuition indicates that if the patterns are changed too rapidly, no useful information will be transferred from the VTA. This is because it takes a certain amount of time to perceive the vibratory pattern applied. The test system must be capable of keeping the pattern of stimulation constant at least for the duration required for recognition of the patterns. It should be able to vary the duration from infinity (i.e. an unchanging pattern) to faster than the vibratory system can perceive in order to test the parameter exhaustively.

Adaptation and recovery times. When a vibratory stimulus of intensity slightly greater than threshold is first applied, it is very clearly sensed. However, after a short time (on the order of one second), the stimulus becomes almost imperceptible. This effect is called "adaptation". It is thought to be caused by a decreased sensitivity of the vibration sensors produced by their stimulation. Once stimulation ceases, the sensitivity begins to recover. The length of time required to return to near normal sensitivity is called "recovery time". This parameter is important in timing the presentation of stimulus patterns for their optimal perception. The test system must allow adjustment of these parameters in order to test the response of the tactile vibratory system.

Number of distinguishable levels. This corresponds to the number of shades of gray perceptible in a visual image. This parameter affects the amount of intensity information which can be usefully presented. The minimum useful intensity for perception of stimulation is the stimulus threshold. The strength of the stimulus can then be increased until a new level of sensation is perceived which is clearly distinguishable from the previous level. This is a just noticeable difference (JND). The number of JNDs between threshold stimulus intensity and maximum tolerable stimulus intensity is the number of distinguishable intensity levels of the sensory system. In practice, the upper limit of stimulation intensity is the maximum which can be safely provided by the

transducers which make up the VTA. An operational appliance for vision substitution should make use of the maximum range of usable perception available. The test system should be capable of providing stimuli over a wide range of levels, from two intensity levels (zero and some selectable intensity up to the maximum allowable) to beyond the number of levels which can be perceived as different.

Temporal correlation between stimuli. Vibratory stimuli at adjacent sites could be presented at the same frequency and with a constant phase difference in their movements (that is, temporally correlated). As an alternative, the relative phase could be varied in some fashion with time, presenting stimuli which are temporally less correlated or uncorrelated. The test system should be capable of providing temporally uncorrelated driving signals to the stimulators.

Parameters which depend on electrical and mechanical characteristics of the VTA. Since the VTA to be used had already been designed and built before the start of this research, its electrical and mechanical parameters were fixed and served as predefined design constraints [9].

Current or voltage range required. This is the range of current or voltage required to produce vibratory stimuli over the range of perceptible intensities. It depends on the type of transducer used (eg. electromagnetic, piezoelectric), the specific

characteristics of the transducer, and the coupling of the active element of the transducer with the skin. Displacement produced by electromagnetic transducers, such as those used in the VTA, is proportional to current, while in piezoelectric transducers, it is proportional to voltage. The test system must provide sufficient current to drive the electromagnetic transducers in the VTA.

Impedance of transducers. This is the ratio of applied alternating voltage to resulting alternating current for the transducer within the intended operating range and at the operating frequency. It may have an imaginary component. This governs how much voltage is required to produce the current needed for required displacements.

Size of the transducers in the VTA. This limits the spacing of the transducers in the VTA, and therefore the total number of sites which can be stimulated. The maximum number of sites which can be stimulated is equal to the total skin area available for stimulation divided by the surface area of one stimulator. The size and number of transducers in the VTA also determines heat production, cost, and physical flexibility of the entire VTA (important because the VTA must conform to the compound curves of the body). Other relevant factors are discussed by Kovach [9]. The dimensions of the transducers are less important to the driving test system than is the total number of transducers to be controlled.

<u>Number of transducers.</u> This parameter affects the spatial resolution which can be produced by the VTA. The number of pixels which can be presented in a pattern is equal to the number of transducers, since one transducer can only vibrate at one particular intensity at any one particular skin location at any given time. Therefore, the detail which can be presented is controlled by the number of transducers in the VTA. The test system must be able to drive all of the transducers individually, and to produce a pattern with as many pixels as there are transducers.

<u>Power consumption.</u> The amount of power required to drive each transducer of the VTA affects the total power requirement of the device. This affects the device's portability since it determines the size of the portable power source needed and the length of time a rechargable power source could go between charges. It also affects the amount of heat generated by the device. The allowable heat production is limited to that which can be dissipated while keeping the VTA at a temperature comfortable to the wearer. Since the VTA must be worn against the skin and beneath the clothing, the dissipation, and therefore the allowable heat production, are quite limited. The test system will be used to evaluate the allowable power levels.

<u>Maximum ratings.</u> This refers primarily to current and power which the transducers in the VTA can safely handle. These values govern the maximum intensity of stimulation which can be provided at

any one site, and so limit the total number of levels of stimulation which are available. (See Number of distinguishable levels, above.) The test system should never drive the transducers with more than their rated current or power.

Effect of loading. The skin pressing against the moving portion of the stimulator (transducer) adds to the mechanical load to be driven, damping the motion. This increases the power required to move the stimulator element. The extent of this effect depends on the mass of skin actually moved by each stimulator element, the coupling between the stimulator element and the skin, and the relative mass of moving material in the unloaded stimulator element. The test system must be able to provide sufficient power to each transducer in the VTA to overcome the effect of loading and to drive the transducer to the required motion.

Methods Used to Determine the Required Ranges of Parameters

Vibratory deformation required for perceptible sensation. The amount the skin must be deformed to produce a perceptible sensation depends on the location of the skin selected for the vibration (the tip of the finger is more sensitive than the middle of the back, for example) and on the frequency of the vibration. Mountcastle [10] states that for stimuli less than 8 dB greater than threshold, the skin's vibratory sensors are not capable of frequency

discrimination. Wilska [11] found the threshold amplitude to be 40 micrometers for detection of vibration on the skin of the abdomen. Based on this data, Kovach [9] calculated that 200 micrometers of vibratory amplitude at 200 Hz would be sufficient for perception of spatial patterns. The transducers of the VTA constructed by Kovach can produce an easily discernible vibration when operated within their normal current and power dissipation ranges.

Frequency of stimulation for maximum sensitivity. Rogers [8] established that, at least for the glabrous skin of the hand, the optimal frequency for detection of vibratory stimulation was 200 Hz or slightly higher. Our initial experiments indicate it is closer to 260 Hz. However, what may prove the best in terms of transfer of information about spatial patterns may not be the frequency at which maximum sensitivity is obtained for stimulation of a single point. Therefore, the test system should be capable of providing a continuously variable frequency of stimulation from below 200 Hz to above 260 Hz. In case this range proves insufficient, the system should be easily modified to produce stimulation at other frequencies.

Spacing between stimulated sites on the skin. The two-point threshold for the trunk (the minimum spacing required for two stimuli applied to the skin simultaneously to be perceived as distinct) has been given as 6.8 cm [12]. Yet, stimulator arrays have been used with a spacing of only 12 mm [7] and have been shown

not to be redundant. The optimum spacing for transfer of information about spatial patterns is not known, but is probably less than the minimum spacing for two-point discrimination. The minimum spacing available for this research is fixed at 12 mm by the size of the transducers used in the VTA. Greater effective spacing can be obtained, however, simply by using only those transducers located the required distance apart. This does place on the test system the requirement of allowing selection of the individual transducers to be activated. A programmable device for selecting the individual transducers to be activated would be the most convenient arrangement for research purposes.

Required duration of stimulation. We did preliminary experiments using manual selection of the active elements in the VTA, via a 16 by 16 array of selectable contacts, each wired to one transducer in the VTA. The results indicate that it takes at least one half second for a subject to recognize a spatial pattern presented by th VTA. Therefore, it will be assumed that the test system need not present more than three different patterns per second. The test system should have the capability of keeping a selected pattern on the VTA as long as desired.

Adaptation and recovery times. These are not parameters which can be varied; rather they are constraints imposed by the properties of the physiological system stimulated upon the test system. Because the tactile system adapts to the vibratory stimulus in about

one second, keeping the same pattern on the VTA without interruption would seem to reduce the information transfer to the wearer. Since the tactile system exhibits a recovery time on the order of one second or longer (depending on the strength of the initial stimulus), there should be some time during which no stimulus is presented. Professor Lipetz suggested modulating or gating the presentation of the stimulus pattern with a low frequency signal of about 0.2 to 6 Hz. This would present the pattern for a short time (half the period of the low frequency gating signal) and allow it to be perceived. Then the stimulation would be "turned off", allowing the receptors in the skin to recover during the remainder of the period. The system which drives the VTA should therefore be capable of gating the patterns presented to the VTA at a maximum rate of 6 per second, with a minimum rate of not more than 0.2 Hz. Programmable selection of the temporal pattern of activation of the VTA would be most convenient and flexible.

Number of distinguishable levels. The number of distinguishable levels of stimulus intensity directly controls the number of bits of data which can be presented to each stimulated skin site and, therefore, to the entire array:

$$b = p \log_2(n) \qquad \text{(Eq. 2-1)}$$

where b is to total number of bits of data in each frame or pattern presented, p is the total number of points stimulated, and n is the number of distinguishable levels of stimulus intensity at each

individual point. Zero intensity is one level; another is the maximum intensity which can safely be provided by the transducers in the VTA. Our preliminary experiments indicated that only one intermediate level could be distinguished by the skin's vibration sensing system when only one site was stimulated. The test system should be capable of driving the transducers full on, completely off, and at one or more intermediate levels, the intensities of the intermediate levels being controllable.

Temporal correlation between stimuli. Our initial experiments using manually selected control of the VTA indicated that spatial patterns of vibration were very difficult to recognize if the adjacent stimuli were temporally correlated in their vibrations. In fact, it was extremely difficult to distinguish between stimulation of single sites and stimulation of pairs of adjacent sites. Professor Lipetz suggested using signals which were uncorrelated in their vibrations to drive adjacent stimulator elements. The test system should be capable providing these signals.

Current or voltage range required. Each transducer in the VTA consists of a small coil of wire around a core of magnetic material. A current through the coil sets up a magnetic field which deforms a metallic disk placed perpendicular to the core. It is this disk which contacts the skin. The displacement of the skin is dependent on the current through the coil. Our experiments with the transducers indicate that a train of rectangular pulses with a

frequency of 250 Hz and a duty cycle (ratio of "on" time to the total period) of 1/16 produced a clearly perceivable sensation at a peak current of 8 mA. At 25 mA peak current, using a 1/16 duty cycle as above, the transducers became slightly warm, and produced a very strong sensation. The transducers are rated at 25 mA peak current. The test system should be able to supply a current of from zero up to 25 mA peak to each of the transducers and be able to modulate that current at frequencies from zero to over 6.0 Hz.

Impedance of transducers. The impedance is of concern only in that it determines the driving voltage needed to produce the desired current through the transducers of the VTA. The desired 25 mA peak current through a transducer was found to occur when a 200 Hz, 1/16 duty cycle, rectangular pulse train of 10 V peak voltage was applied. Thus, 10 V peak suffices as the driving voltage to be supplied by the test system.

Size of the transducers in the VTA. This is fixed. The transducers used in the VTA are cylindrical, approximately 12 mm in diameter and 5.4 mm long, not including the leads.

Number of transducers in the VTA. This is fixed at 256, arranged in a 16 by 16 array. The test system must be capable of supplying drive current which can be controlled and modulated to each of the 256 transducers simultaneously.

Power consumption. Using a duty cycle of one half, Kovach was able to produce perceptible stimulation with one transducer

consuming 20 mW. If a duty cycle of one half were used, and if the transducers were driven by uncorrelated signals, the average current required would be 3.2 A, assuming all transducers were being driven at their maximum level of 25 mA. This is because on the average, only half of the uncorrelated signals with a duty cycle of one half will be on at any one time. However, the power source would have to be capable of supplying a maximum peak current of 6.4 A, at the instants when all the driving signals were on at the same time.

A method of reducing power consumption without reducing the intensity of the stimulus would provide longer battery life for a portable version and would significantly reduce the heat generated. We found that with a duty cycle of 1/16, threshold stimulation was produced with as little as 1.6 mW average power in one transducer. For 256 transducers this would require 0.41 W average, with a maximum current of 0.2 A; a significant reduction. The test system should incorporate a method of exploring the amount of useable power reduction provided by a reduction in duty cycle.

Maximum ratings of the transducers are given as 12 V, 25 mA each. The test system should not exceed this maximum rating.

Effect of loading. Loading the transducers with the skin alters the impedance somewhat. We applied a square wave voltage at 260 Hz to four transducers while observing the resulting current's wave shape displayed on an oscilloscope. When loading was increased by pressing the transducers against the skin, the resistive

component of the impedance increased, but the inductive component decreased slightly. Ten volts was sufficient to drive a loaded transducer to its 25 mA rated peak current. The test system must be capable of providing at least that voltage.

CHAPTER III

RATIONALE FOR SELECTED DESIGN

Introduction

In this chapter, the options available in designing the test system for driving the VTA will be described. The design choices and trade-offs will be related to the system constraints which were given in Chapter II.

Even though this test system is intended primarily as a laboratory tool, it should conform to the design constraints which would apply to an appliance meant for the user, wherever this can be done without affecting the versatility of the device as a test instrument. This is so the system can be used to evaluate both the parameters and the technology being used. Therefore, these considerations are included wherever applicable.

Figure 1, Overall Block Diagram of the Test System, shows the final selected configuration.

General Considerations

The test system should be built from off-the-shelf hardware and not rely on any exotic technology or on items with limited availability.

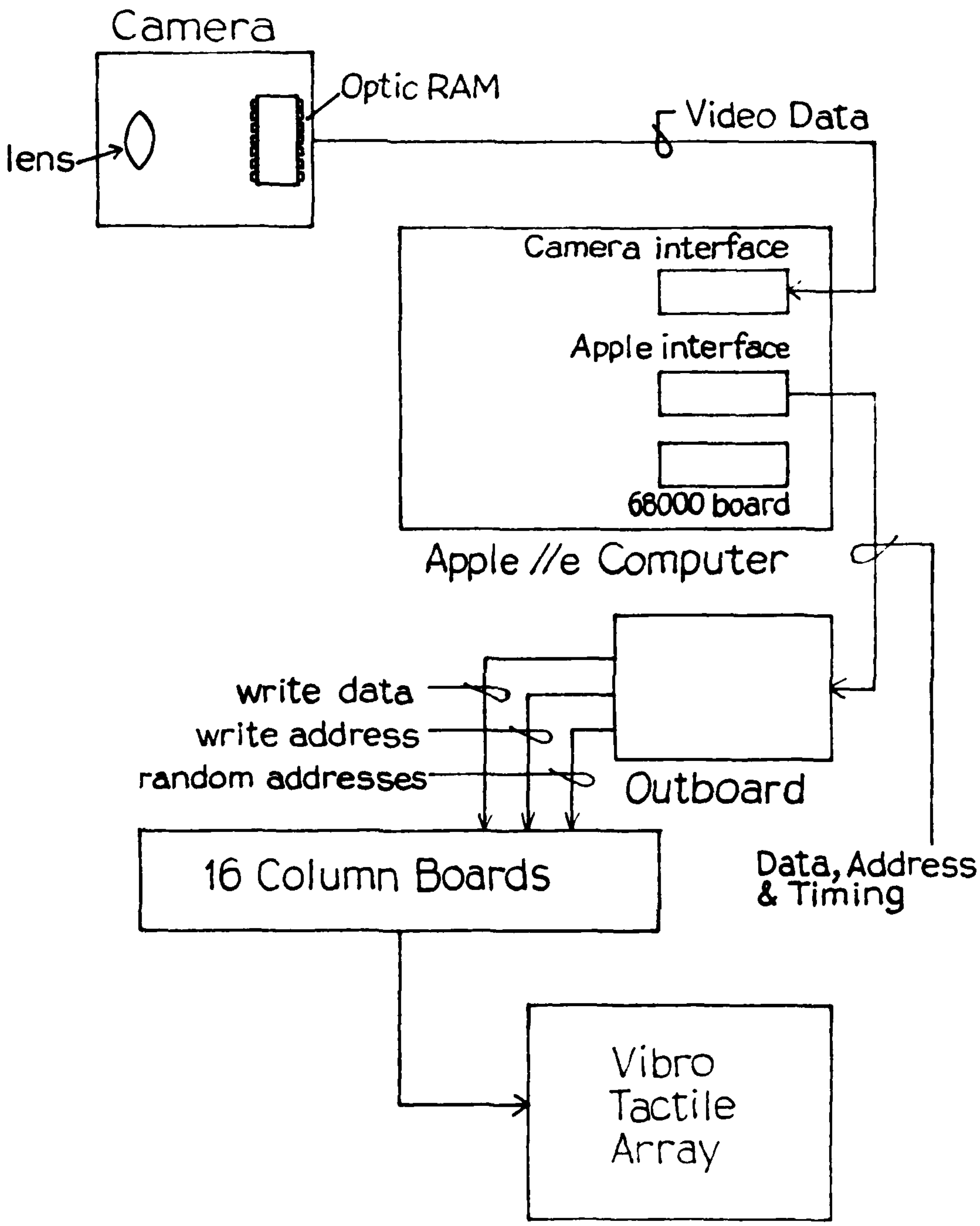
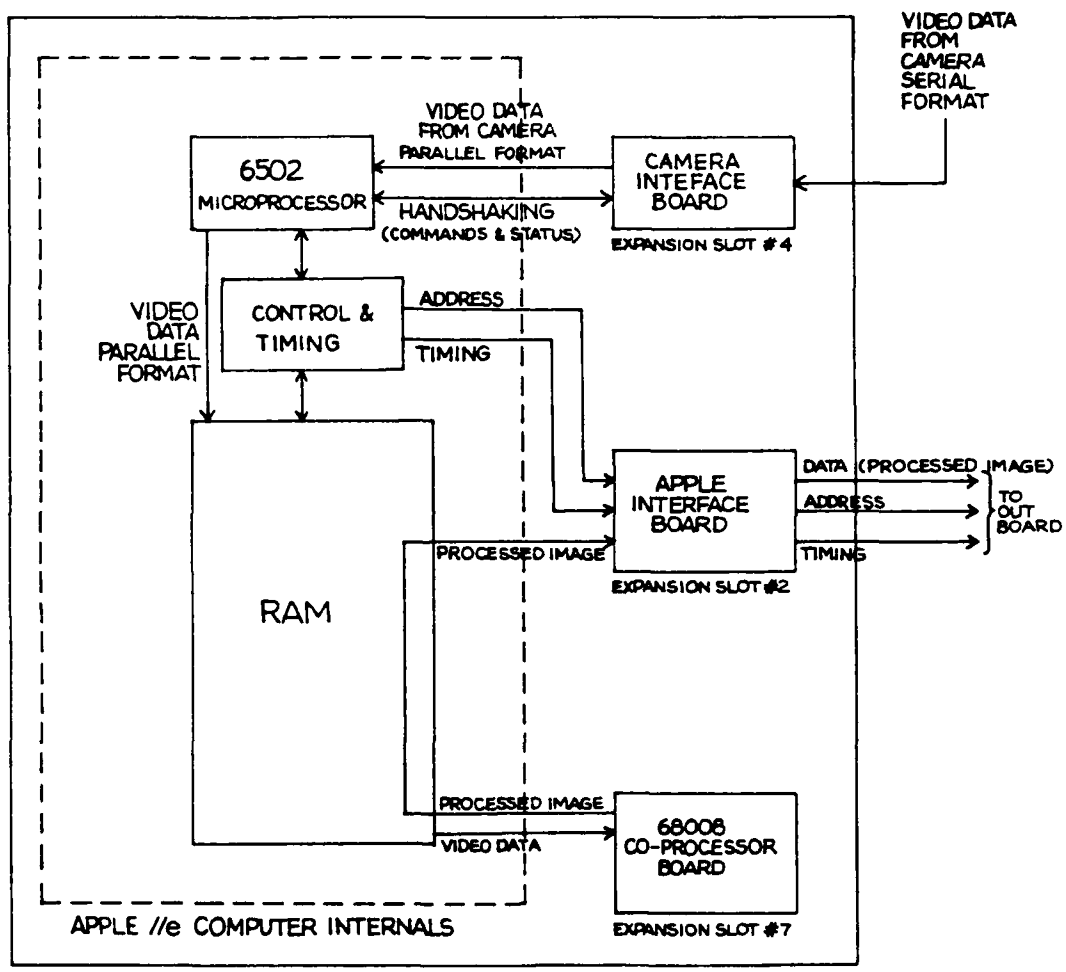


Figure 1 - Overall Block Diagram of the Test System

Figure 1 (Continued)



APPLE //e COMPUTER: EXPANDED VIEW

The total cost should be kept to a minimum. It should come as close as possible to being a usable appliance, while still providing the flexibility required in a piece of test equipment.

Camera

The camera is the input or sensor for the system. It must convert an optical image formed with normal ambient light into an electronic signal. This signal, after appropriate processing, will be used by the test system to drive the VTA. The pattern of vibration exhibited by the VTA must depend on the camera's image.

The camera should be capable of producing images which are visually recognizable. This is because the ultimate goal of the system is to serve as a substitute for vision for the blind. Therefore, sufficient resolution at least to produce recognizable images is needed. Finer resolution, like that produced by a high-quality video camera for television, is not needed since only 256 picture elements, or pixels, can be presented by the VTA.

The camera's output should be of a form which allows it to be easily read by or entered into a computer. It is clear that some processing will have to be done to produce the 256-pixel pattern to be presented by the VTA. For experimental purposes some sort of computer control of the processing would be advantageous. This will be discussed in detail below. Therefore, a camera which is easily connected to a computer and is compatible with a computer's input format would be prefered.

Physically, the camera should be small, lightweight, and rugged. It should be head-mountable so as to parallel as closely as possible the normal process of looking about the environment. This way, the environment will be scanned by the wearer of the VTA by moving the head, simulating the way sighted people scan. Small size and low weight are necessary for it to be mounted on the temple piece of glasses or on a headband. In addition, it should be rugged to resist damage from motion of the head and the possible jarring. This means that both the external housing and the light-sensing element itself should be relatively immune to vibration and mechanical shock.

In order to become an accepted appliance, the system cost should be kept to a minimum. Therefore, the camera should be inexpensive and readily available. High technology devices which are expensive or difficult to obtain, even though they might possess desirable characteristics, could prevent such a system from gaining user acceptance. Therefore, the camera should not rely on anything other than inexpensive and readily available components.

Details of Camera Implementation

Types of cameras available. The primary sensor types for video cameras are the vidicon tube, charge-coupled devices, and optic RAM. Each of these will be discussed in detail.

The vidicon tube is a vacuum tube with the physical characteristics necessary to allow focusing an image on a light sensitive area of the tube. Electrodes inside the tube allow scanning the optical image to produce a voltage which varies in proportion to the light intensity at the point of the image which is being scanned. Vertical and horizontal synchronizing information is added by electronic components in the camera. The resolution is very high. Broadcast quality television cameras use the vidicon tube as the sensor. Vidicon tubes are fairly expensive, heavy, fragile (because of the glass bottle containing the high vacuum), and have a large power requirement. In addition, vidicon tubes require high voltages for operation, which could pose a hazard to a wearer in wet environments.

The charge-coupled device, or CCD, is a solid state imaging device. The resolution is quite high, though not as high as that of which the vidicon is capable. Some home video cameras use CCDs as the sensing element. The element itself is relatively small and rugged. However, CCDs are quite expensive and require complicated drive circuitry.

The optic RAM (Random Access Memory) is a solid state integrated circuit chip which can produce an electrical equivalent in digital form of an image focused on it. It is identical in internal construction to dynamic RAM chips used in computer memories, but is packaged in a transparent plastic case to allow

focusing of an image on the active element. The entire integrated circuit occupies less than 0.05 cubic inches [13], not including leads. It is extremely rugged, lightweight, and costs less than $50. Since the output is digital in format, it can be interfaced easily to a computer.

Because the optic RAM is small, lightweight, rugged and readily available, it was selected as the input sensor for the test system. A complete camera system, called the Micro-D Cam, including lens, tripod, and interface for an Apple //e or IBM PC computer, costs $250 and is available from Micromint, Inc., 516 Willow Ave., Cedarhurst, NY 11516. This camera produces an image with up to 32,768 pixels in a 256 by 128 format. It produces up to 15 frames per second, depending on the exposure time dictated by the ambient light level. The camera is a cylinder 1.5 inches in diameter and 4.25 inches long. A much smaller camera which is electrically interchangable with this one can be constructed using the optic RAM chip itself and a small plastic lens.

<u>The camera interface.</u> The output from the camera is serial data at software-selectable rates up to 153,600 baud. The camera interface plugs into an expansion slot in the back of the computer and converts the serial data to parallel format for the computer's use. The interface has a data port to simplify sending commands to the camera to specify exposure time. In addition, this port allows easy checking of the status of the camera interface and selection of

data rates and format. These parameters are used by the program which controls the camera's activity and stores the camera's image in the computer's memory. The program which does this is shown in Table 2 [14].

Processing Subsystem

The processing subsystem, or processor, is required to convert the output of the camera into a form which will be usable by the driver of the VTA. It could be hardwired (i.e. with the function, including image-processing algorithm, predetermined and fixed) or programmable, allowing changes to be made merely by changing the program being used.

The primary task of the processor is to convert the relatively high-resolution image produced by the camera to a 256-pixel image or pattern which can be presented by the VTA. It must possess some algorithm or rule for doing this conversion. It must have a method of storing the camera image and the algorithm.

For test purposes, the processor should be programmable to allow testing of different algorithms for transforming the camera data. In addition, programmability would allow testing with entirely artificial patterns.

As mentioned in Chapter II, the camera and processor together should be capable of producing up to two or three processed images per second. With a programmable processor, this could be slowed down as much as required for testing.

For test purposes, at the option of the experimenter, the processor should be capable of providing a display of the image being produced by the camera. This is to facilitate aiming and focusing the camera, and to improve the experimenter's ability to interpret test subjects' reactions.

Details of the Processing Subsystem

There are many computers currently commercially available which would perform the processing task adequately. Since the camera selected is available with an interface for either the Apple //e or the IBM PC, these were natural candidates. The Apple //e was selected because of the author's previous experience with interfacing techniques for the Apple //e and the possesion of advanced programming tools for that computer, including a BASIC editor, a BASIC compiler, and an assembler.

The Apple //e alone could just meet the image processing requirements, but by adding a 68000 co-processor board, additional image processing techniques such as edge detection and edge enhancement could be done without a reduction in frame rate. The Q-68 board, a 68008-based co-processor for the Apple //e produced by Stellation II, was selected. It plugs directly into one of the expansion slots in the back of the Apple //e. The microprocessor in this co-processor runs at 7 MHz, approximately seven times the speed of the Apple //e, and can run simultaneously with it. The 6502 microprocessor resident in the Apple //e can then read the camera

data and enter it into memory and send the necessary commands to the camera while the 68008 co-processor does the image processing and data reduction.

The processor must be able to address individually 256 transducers in the VTA. It must be capable of setting the level of stimulation at each of them at one of many possible levels within the operating range. Therefore, the computer requires an interface to connect it to the drive circuitry. This interface is refered to as the "Apple interface board". It was designed and built with the rest of the test system. Like the camera interface and 68008 co-processor board, it plugs into an expansion slot in the back of the Apple //e computer. It provides eight bits of data (i.e. a number between 0 and 255 selectable by the computer) which represent stimulation levels, eight bits of address which select which of the 256 transducers is to receive the current level specified by the eight bits of data, and the required timing signals which allow the drive circuitry to synchronize with the computer to receive the data.

Driver

The driver provides the interface between the processor and the VTA itself. It must be compatible with the programmable processor on one side, and the relatively high-current VTA on the other.

The driver must supply drive current (up to 25 mA per transducer) for the 256 transducers in the VTA, and the level of drive current to each of the transducers must be individually controllable by the processor. The frequency of the driving signal to each transducer should be controllable from less than 200 Hz to more than 260 Hz. The driving signals to adjacent transducers should be temporally uncorrelated with respect to one another.

For test purposes, the driver should provide the experimenter with a visual indication of the pattern of stimulation being presented via the VTA. This provides a quick check to verify operation of the overall system from the camera up to its input to the VTA. It also enables the experimenter to evaluate the effectiveness of the data reduction algorithm being performed by the processor and better interpret the reaction of the test subject.

Details of the Drive Circuitry

The drive circuitry has two primary functions: to interface or buffer the computer signals sent through the Apple interface board (computer-modified data, address, and timing signals), and to provide temporally uncorrelated signals which drive the vibratory transducers of the VTA.

The most challenging task of the design was to find a way to produce 256 uncorrelated signals. Several ideas were considered. These included producing 256 independent oscillators, each with its

own frequency determining circuit. The 256 independent oscillators would not only be expensive to build and use considerable amounts of power, but would greatly increase the parts count, making the device very large.

Another approach was pulsing the transducers with very short bursts of energy causing them to ring and allowing the natural resonant frequency of each transducer, which would be slightly different between any two, to produce slightly different and uncorrelated stimulation. Pulsing the transducers was not a good solution because the resonant frequency for the transducers was too high (about 2 KHz) and because it was believed that the vibrations would decay too quickly to be clearly felt.

A third approach was scanning each column of the VTA, activating only one stimulator at a time in some random fashion different for each column. This method was selected and implemented.

The driver circuitry is located in two physically different places. One is called the outboard and the other is a card cage containing 16 column boards. The column boards connect directly to the VTA and provide the current signals which actually drive the VTA. The column boards store the data which control the level of stimulation to be presented at each transducer location of the VTA. The column boards also provide a visual indication of the pattern of stimulation being presented. The outboard buffers the signals from

the Apple interface board and generates the random addresses needed by the column boards, as described below.

Data storage on the column board.

The heart of the column board is the static RAM. Static RAM was chosen because, unlike dynamic RAM, it does not require refreshing to maintain the data stored, thus simplifying the circuitry. The RAM had to have at least 16 locations for storing data, and had to have at least eight bits per location, since the data to be stored in the RAMs was the level of stimulus intensity (or transducer current) required at each VTA location. Each eight-bit piece of data representing a stimulus intensity level is called a word. The RAM also had to have a speed of at least 500 nsec in order to respond to the timing signals generated by the Apple //e. The RCA CDP 1824 was selected, since it was the only available RAM which met these criteria.

Once the data words are stored in the 16 memory locations in the RAM on the column board (the process for doing this will be described below) random addresses generated by the outboard are fed to four address lines of the RAM. The fifth address line is always grounded, since the CDP 1824 is actually capable of storing 32 words, and only 16 were needed. The random address selects, at random, one data word corresponding to stimulation level for a particular VTA transducer.

<u>Conversion of data words to transducer current</u>. The eight-bit data output of the RAM is connected directly to a digital to analog converter (a DAC0808 was chosen because of its low cost, conversion time not being critical). The output of the analog converter is a current proportional to the eight-bit binary number presented to it at its input terminals, in this case, the data word corresponding to the desired stimulation level of the transducer selected by the random address. This random address is also fed to the address inputs of a 16-channel analog multiplexer (an RCA 4067B, chosen because it was the only one available). The multiplexer has sixteen different outputs which are connected to the one input based upon what address is electronically selected. The output of the digital to analog converter is amplified by an LM 1458 operational amplifier, which was chosen because of its low cost and small size. The amplified signal is fed to the input of the 16-channel multiplexer. The 16 outputs of the multiplexer are connected to 16 operational amplifiers each of which drives a transistor. The 2N2906 PNP transistors were selected because of their ability easily to handle the 25 mA required and their low cost. One transducer of the VTA is connected to each transistor's collector, which provides the current to the transducer. In parallel with each transducer is connected a light emitting diode (LED) with a current limiting resistor. Figures 3 and 4 show the signal and address flow.

To summarize, each column board drives one column of 16 transducers in the VTA, controlling the current to each one individually. A four-bit random address selects one data storage location out of the 16 on each column board. The data word previously stored in RAM at that location is converted to analog form and directed by the multiplexer, with appropriate amplification, to the transducer which corresponds to the four-bit random address. By supplying each column board with a different random address, the adjacent transducers are driven by uncorrelated signals. The LEDs provide a visual indication of the level of stimulation at each transducer, and therefore, of the overall pattern being presented.

Random address generator on the outboard. The outboard provides the random addresses and buffers the data, address and timing signals from the Apple interface board. The random addresses are generated by a pseudo-random noise generator consisting of an eight bit shift register (SN74164) and an exclusive-or gate (SN7486). The shift register is capable of storing eight binary digits (bits) in locations called Q_A through Q_H. Each time the shift register receives a clock pulse, the bits move to the next location. The one in Q_A moves into Q_B, the one in Q_B moves into Q_C, and so on. The bit in Q_H is discarded. The bit which moves into Q_A is the exclusive-or of the bits previously in Q_A and Q_G. Exclusive-or is a binary function defined as a binary 1 if

the two inputs are different, a 0 if they are the same. The shifting process produces a linear, maximal length code in locations Q_A through Q_G. The bits which appear in Q_H are not strictly a part of this sequence, so they must be used with care.

The maximal length code has the property that all combinations of 1s and 0s will appear, except all 0s. (If the shift register starts out with all 0s, this condition will continue, since 0s are the result of the exclusive-or operation of 0 with 0, and more 0s are fed into the input. That is, the all-zero state is perpetual. A circuit is provided to prevent this when the system is powered up.) The eight outputs are buffered with an SN74LS244. Groups of four of the outputs are selected at random (with the caveat about Q_H above being noted). Sixteen of these groups of four comprise the sixteen random addresses which are provided to the column boards.

Internal clock on the outboard. Since there are sixteen transducers driven by each column board, and since each transducer is pulsed one sixteenth of the time on the average, the clock driving the shift register must run at sixteen times the desired stimulation frequency. Therefore the clock must run from less than 3200 Hz to more than 4160 Hz. An NE-555 oscillator was configured to provide the required timing, since the NE-555 is stable, easy to use, inexpensive, and oscillates over a wide range of frequencies.

Data buffering on the outboard. The outboard also buffers signals from the Apple interface board to allow the Apple //e

computer to store data in the column board RAMs. The Apple interface board is so wired as to appear to the Apple //e computer to be 256 memory locations starting from $C200 (the "$" indicates hexadecimal notation), or 49664 decimal, and ending with $C2FF, or 49919 decimal. When the Apple //e computer stores a number to a memory location within that range, the number is actually stored in the RAM on one of the column boards. This is accomplished in the following fashion.

The Apple interface board decodes the address bus of the 6502 which is resident in the Apple //e computer. This bus consists of sixteen lines (conductors). The set of 16 simultaneous signals on these lines indicate the address the computer is reading from (when getting data) or writing to (when storing data). Whenever the Apple //e computer accesses locations between $C200 and $C2FF, the hexadecimal number $C2 appears on the high-order eight lines of the address bus. The Apple interface board decodes these eight lines to detect the presence of the $C2 number, telling it that the computer has accessed a memory location between $C200 and $C2FF.

Another line inside the Apple //e computer, called R/W', or READ/WRITE, goes low (i.e. the voltage drops from its normal 5V to very close to zero) when the Apple //e computer attempts to store data at any location. This signal is ANDed with the signal which indicates access to the $C2XX locations as described in the preceding paragraph. The coincidence of those two signals produces

a third signal, "BSEL", which is active only when a WRITE to a location between \$C200 and \$C2FF occurs. The outboard uses this BSEL signal as described below.

The outboard decodes address lines A<4> through A<7>. This is called the high-order nibble of the low order byte, and corresponds to the "X" in the hexadecimal number \$C2XY. These four lines are used to specify which column is to be written to. There are sixteen lines on the outboard, each one of which becomes active when this digit is set to the corresponding value. That is, there is one line which is active when the Apple //e computer addresses a hexidecimal number with 0 in the second place, another which becomes active when a number with a 1 there is addressed, and so on. These lines are all ANDed with BSEL individually, to produce sixteen lines which indicate that a specific column board has been addressed. These lines are designated BSEL·N, where N runs from 0 to 15. They are used by the respective column boards to gate the data and address from the Apple //e computer via the Apple interface board into the RAM.

In summary, whenever the Apple //e computer stores data to locations of the form \$C2XY (where X and Y each run from 0 to F, hexadecimal, 0 to 15 decimal) the number stored is actually stored in location Y on column board X. In this way, any selected value or level of stimulation can be specified and stored for any of the 256 VTA transducers. Since initial experiments indicated that only

three different levels of stimulation could be perceived, only four bits of data, corresponding to 16 levels of stimulation from 0 to 15, have actually been connected. This saves one integrated circuit per column board and still provides a large range of values of stimulus intensity or transducer current.

Table 2 - Camera Control and Access Software

```
* CAMERA ROUTINE
             ORG  $1000
STATUS     =      $C08E
DATA       =      $C08F
SOAKTIME   =      $300
SLOTADR    =      $302
ROWSTART   =      $303
RADR       =      $6
CTR        =      $8
YREG       =      $19
*
START        JSR  ACIACLR
             LDA  #$D3        ;SEND CMD TO SOAK W/O SEND
             JSR  SENDCMD
             JSR  SOAK
             LDA  #$C0        ;SEND IMAGE W/O SOAK
             JSR  SENDCMD
             LDX  #0
NEWROW       LDY  #0
             LDA  ROWPTR,X
             CLC
             ADC  ROWSTART
             STA  RADR
             INX
             LDA  ROWPTR,X
             STA  RADR+1
             INX
GET          STY  YREG
             LDY  SLOTADR
LOAD         LDA  STATUS,Y
             LSR              ; > 7F MEANS BYTE AVAILABLE
             BCC  LOAD        ; IF BYTE AVAILABLE, BRANCH
             LDA  DATA,Y      ;WHEN BYTE AVAILABLE, GET IT
             LDY  YREG        ;RESTORE COL PTR TO Y
             STA  (RADR),Y
             INY              ;INCREMENT COLUMN PTR
             CPY  #37         ;END OF THE COLUMN?
             BNE  GET         ;IF NOT, GET THE NEXT BYTE
             CPX  #$80        ;OTHERWISE
             BNE  NEWROW      ;IF NOT DONE, GOTO NEXTROW
             LDA  #$D1
             JSR  SENDCMD
END          RTS
```

Table 2 (continued)

```
*
ACIACLR  LDA  #3          ;MASTER RESET ACIA
         STY  YREG
         LDY  SLOTADR
         STA  STATUS,Y
         LDA  #$14        ;1 START, 8 DATA, 1 STOP, EXIT CLK
         STA  STATUS,Y
         LDY  YREG
         RTS
*
SENDCMD  STY  YREG        ;SEND BYTE IN A TO CAMERA
         LDY  SLOTADR
         PHA
SEND1    LDA  STATUS,Y
         AND  #2
         BEQ  SEND1
         PLA
         STA  DATA,Y
         LDY  YREG
         RTS
*
SOAK     LDA  SOAKTIME+1 ;SOAK FOR NUMBER OF MS
         STA  CTR+1       ;SPECIFIED BY SOAKTIME
         INC  CTR+1
         LDA  SOAKTIME
         STA  CTR
         INC  CTR
         LDA  SOAKTIME
         BNE  SOAK1
         LDA  SOAKTIME+1
         BEQ  SOAK2
SOAK1    JSR  MSEC
         DEC  CTR
         BNE  SOAK1
         DEC  CTR+1
         BNE  SOAK1
SOAK2    RTS
```

Table 2 (continued)

```
*
MSEC      STY  YREG          ;ONE MILLISECOND LOOP
          LDY  #199
MSEC1     DEY
          BNE  MSEC1
          LDY  YREG
          RTS
*
ROWPTR    HEX  002000240028002C003000340038003C
          HEX  802080248028802C803080348038803C
          HEX  002100250029002D003100350039003D
          HEX  802180258029802D803180358039803D
          HEX  00220026002A002E00320036003A003E
          HEX  80228026802A802E80328036803A803E
          HEX  00230027002B002F00330037003B003F
          HEX  80238027802B802F80338037803B803F
          HEX  282028242828282C283028342838283C
          HEX  A820A824A828A82CA830A834A838A83C
          HEX  282128252829282D283128352839283D
          HEX  A821A825A829A82DA831A835A839A83D
          HEX  28222826282A282E28322836283A283E
          HEX  A822A826A82AA82EA832A836A83AA83E
          HEX  28232827282B282F28332837283B283F
          HEX  A823A827A82BA82FA833A837A83BA83F
```

CHAPTER IV

SYSTEM VALIDATION AND RESULTS

Introduction

The test system as designed and built meets or exceeds the system design criteria specified in Chapter II. The complete system is pictured in Plate I. The camera is at the extreme right. To the left of the camera is the joystick for controlling computer-generated patterns. The Apple //e computer with monitor is to the left of the joystick. On the platform on the left is the card cage with the 16 column boards mounted vertically inside. The outboard rests on the top of the card cage. In front of the card cage is the VTA. The camera is shown in close-up in Plate II. This chapter details the measured capabilities of the system.

Transferring Patterns to the VTA

That the test system meets the primary goal of transferring patterns from the processor to the VTA is demonstrated on Plates III and IV. Plate III shows on the computer monitor a pattern being generated by a BASIC program for test purposes. Plate IV shows the pattern displayed on the LEDs on the column boards. In this test program, the pattern can be moved under joystick control, simulating the movement of a camera. There is no effective way of showing the

vibration of the VTA itself. However, the transducers can be felt individually to verify that they are activated in correlation with the LED pattern. Plates V and VI show the same items for a different pattern.

Plate VII shows a pattern cut from a piece of paper. The camera was aimed at this pattern. Plate VIII shows the high-resolution image displayed by the computer, and Plate IX shows the LED pattern which results.

Plate X is a photograph of the Venetian blinds which cover the windows in the lab. The camera was pointed at these blinds. Plate XI shows the high resolution image generated by the camera and displayed on the computer's monitor. Plate XII shows the LED pattern which was produced. The correlation of the patterns is clearly shown.

Frequency of Stimulation

The clock, which runs at 16 times the average stimulator frequency, covers the range from 2640 Hz to 4600 Hz. This corresponds to average stimulator frequencies of 165 Hz to 287.5 Hz, which more than covers the required range. Plate XIII shows three traces of the voltage applied to one transducer. The frequency was set to 180 Hz. The period varies with time in a random fashion. Plate XIV shows the transducer voltage with the frequency at 250 Hz.

Uncorrelated Stimulation

The two oscilloscope traces of Plate XV shows the voltages applied to two transducers in the same column during the same time period. The patterns are random and temporally disjoint. Although no detailed analysis of the oscilloscope traces was done to confirm the lack of correlation, it clearly follows from the structure of the address generation logic.

Duration of Stimulation Pattern

At maximum speed, the processor can supply just under two patterns per second to the VTA using the resident 6502 microprocessor. (The 68000 co-processor has not yet been used.) By inserting a loop or a wait-for-keyboard input, the pattern can be left on as long as desired.

Levels of Stimulation

Table 3 shows the peak current through one transducer as a function of the data word stored at the corresponding location in the column board RAM. There are about three usable distinct levels instead of sixteen due to the non-linearity of the driving transistors. This is because the 2N2906 driving transistors saturate at a low level of base current. A more complicated method of biasing would prevent this.

Low Frequency Gating

The low frequency gating is done by the processor under software control. Using the 6502 in the Apple //e computer, the maximum frequency of modulation is just under 2 Hz when using the camera image. The 68000 co-processor board should allow increasing this to better than the required 6 Hz. There is no fundamental limit to the minimum frequency. Plate XVI shows the voltage supplied to one transducer when the signal is being gated at 5.5 Hz. Plate XVII shows the same with 8.8 Hz gating.

Stimulus Intensity

From Table 3, it can be seen the maximum rated current of 25 mA can be sent through the transducers by the driver circuit. Vibrations of the transducer produced by pulses with this level of peak current are quite perceptible to the vibratory sense.

Plate I - Overall View of Test System

Plate III - Pattern on Computer Monitor

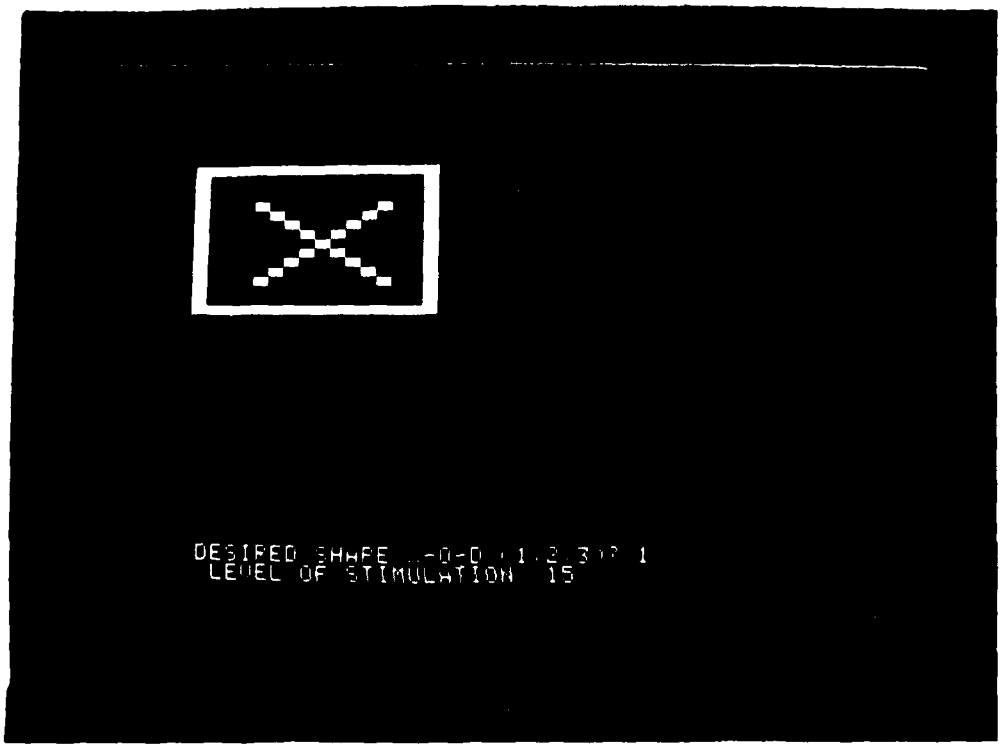


Plate IV - Pattern on LED Display

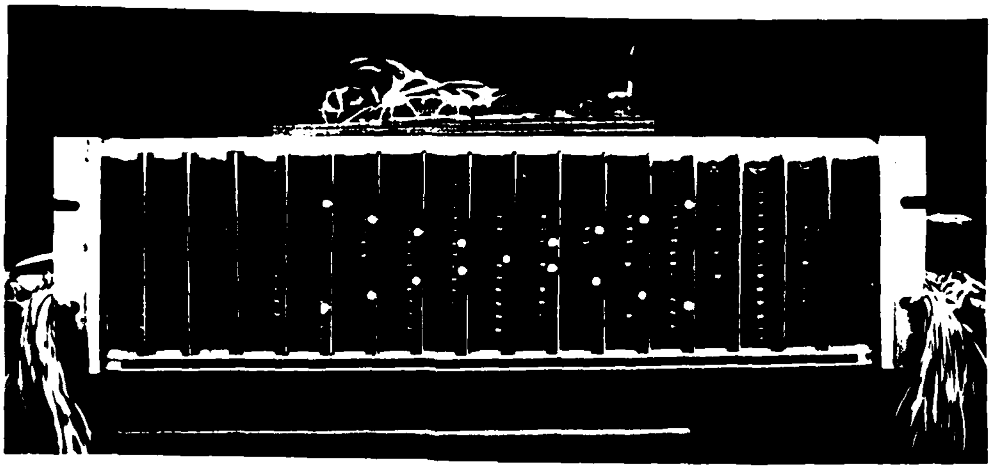


Plate V - Pattern on Computer Monitor

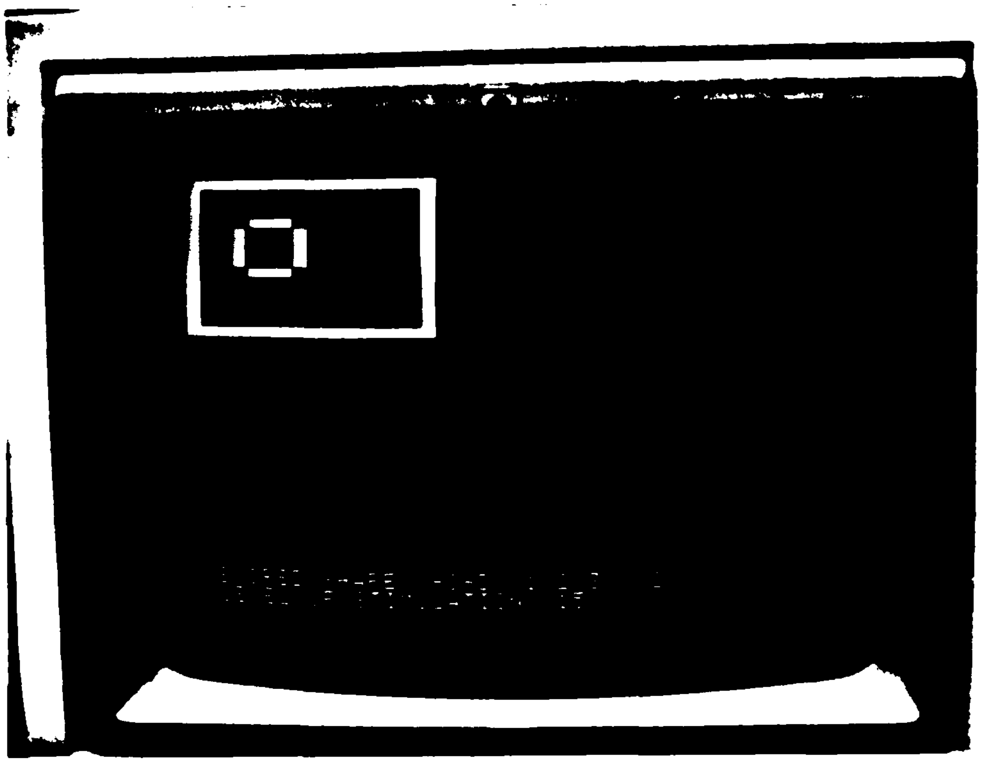


Plate VI - Pattern on LED Display

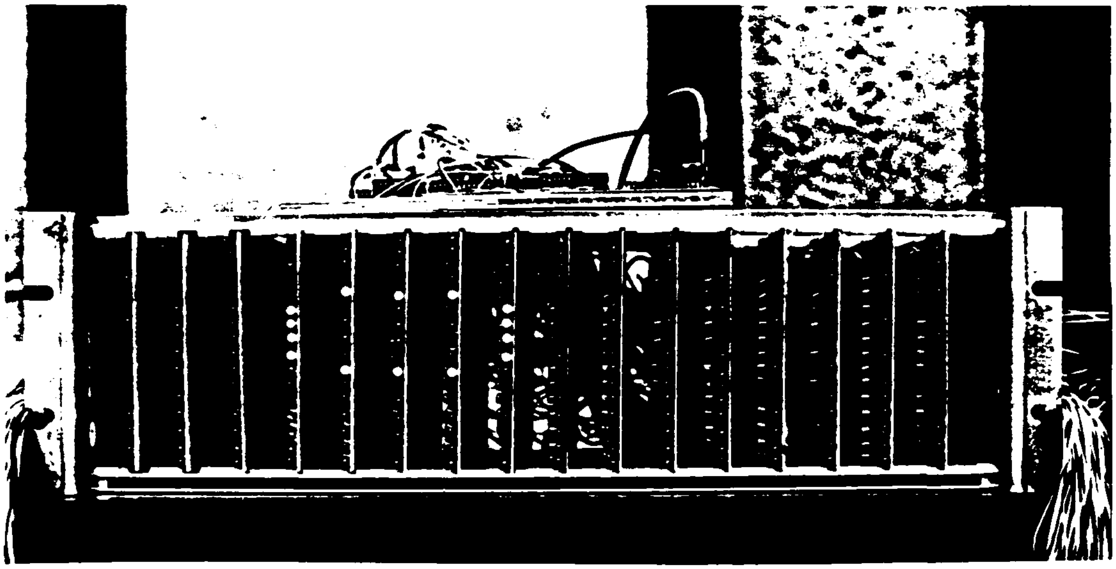


Plate VII - Paper Test Pattern - Actual Size

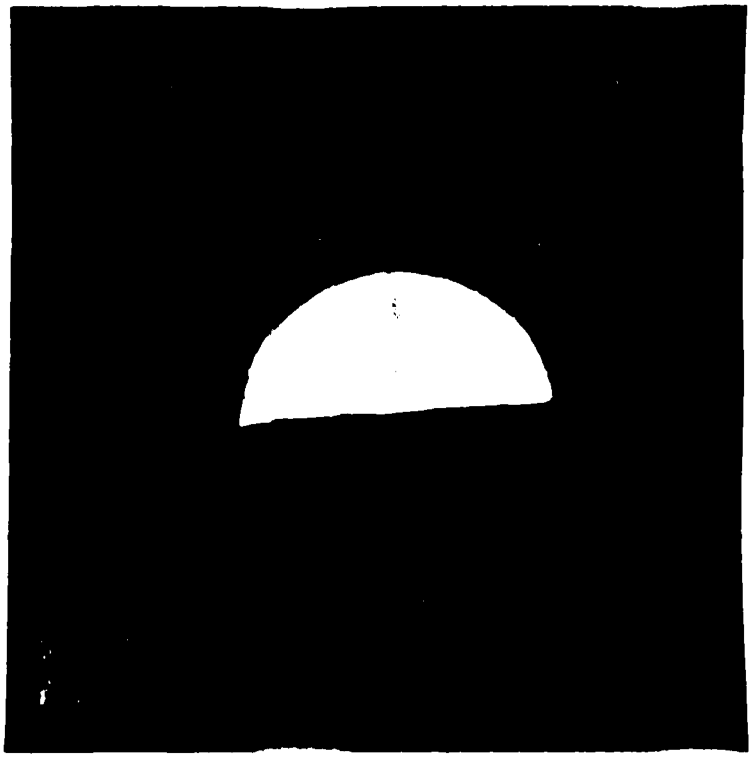


Plate VIII - High Resolution Camera Image of Test Pattern

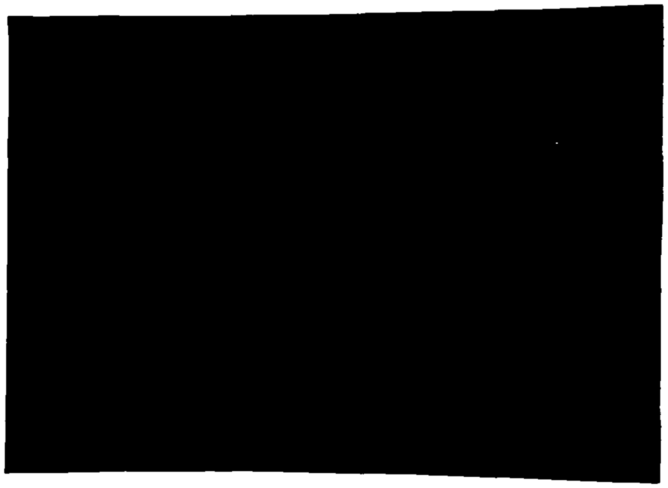


Plate IX - LED Display of Test Pattern

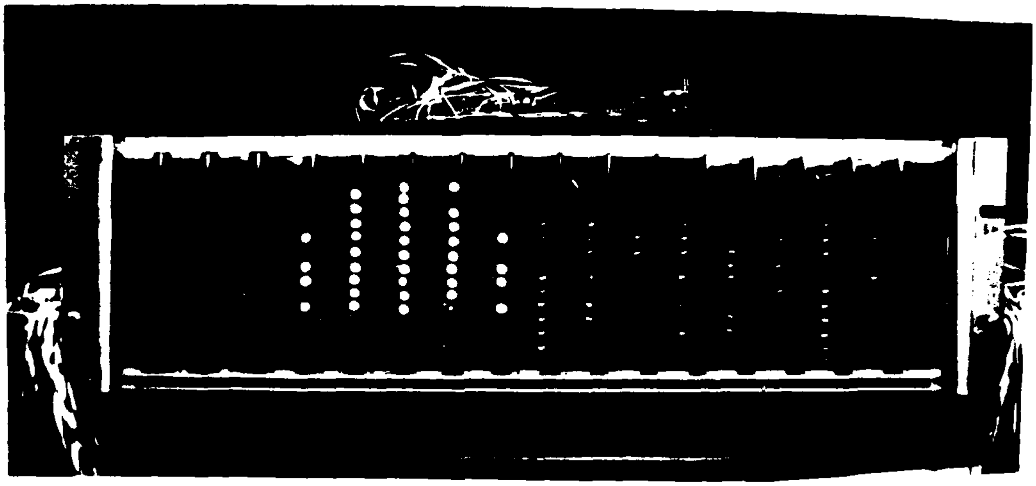


Plate X - Photograph of Venetian Blinds

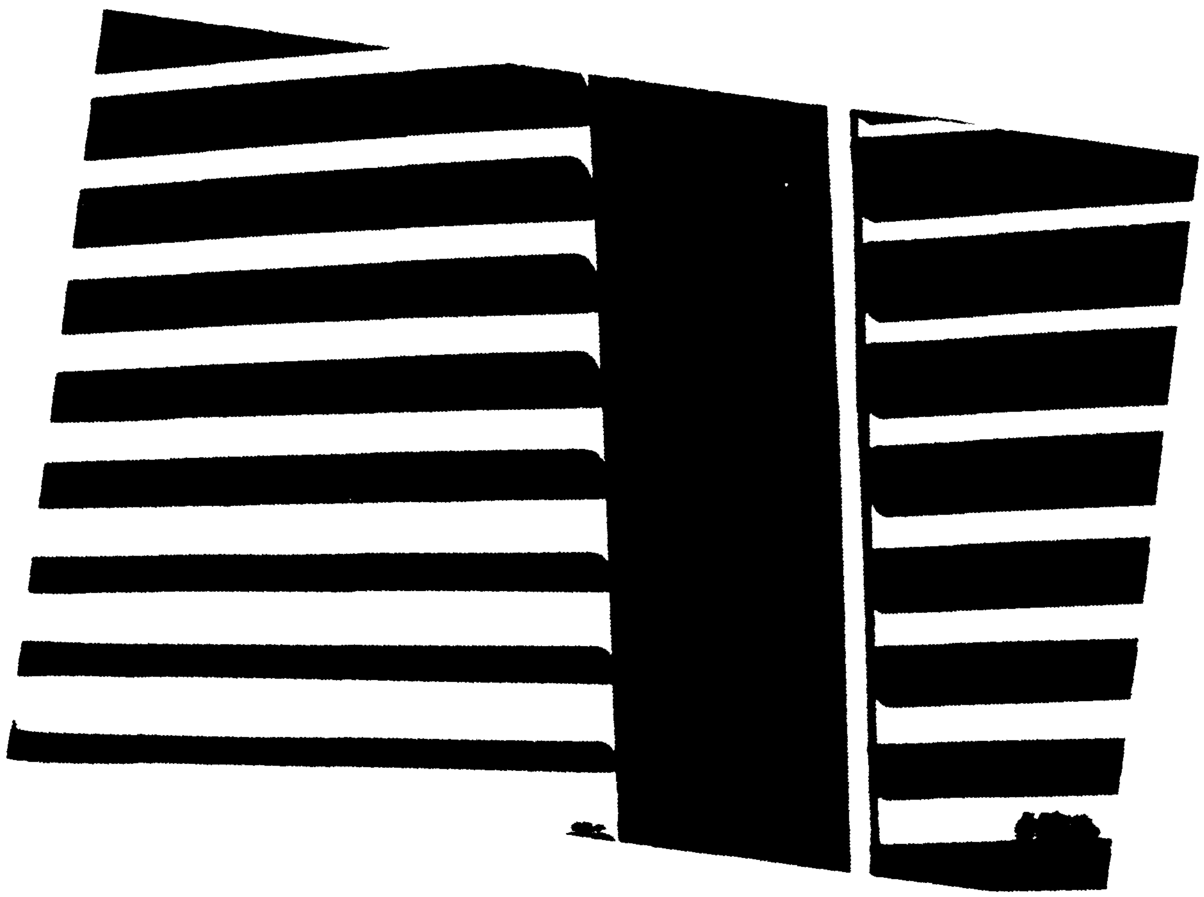


Plate XI - High Resolution Camera Image of Venetian Blinds

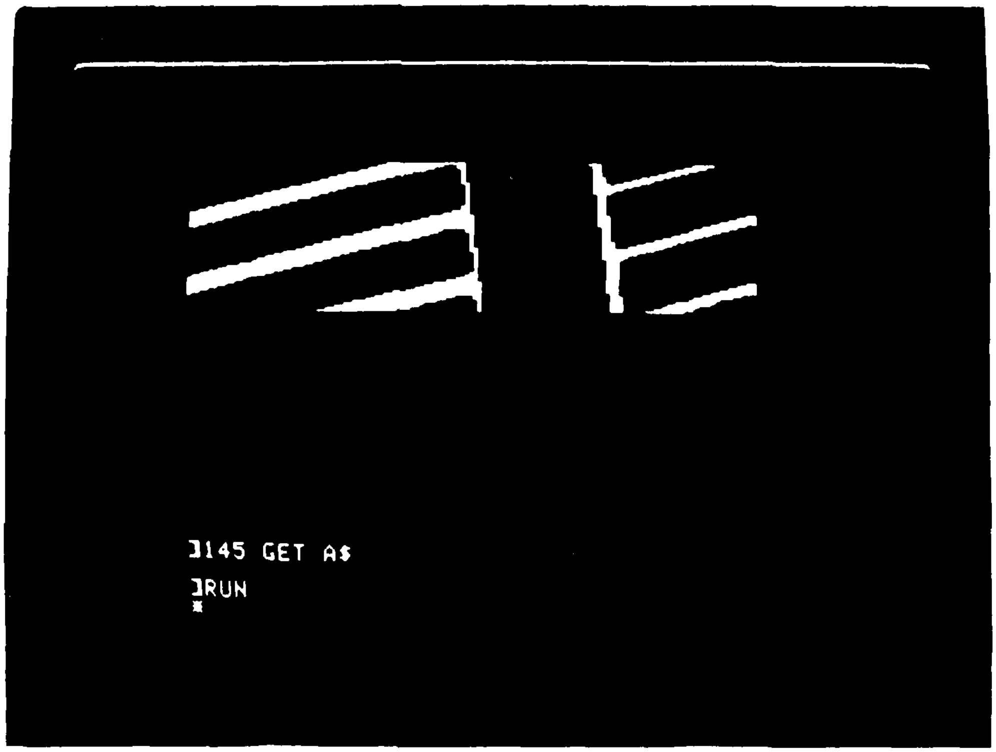


Plate XII - LED Display of Venetian Blinds

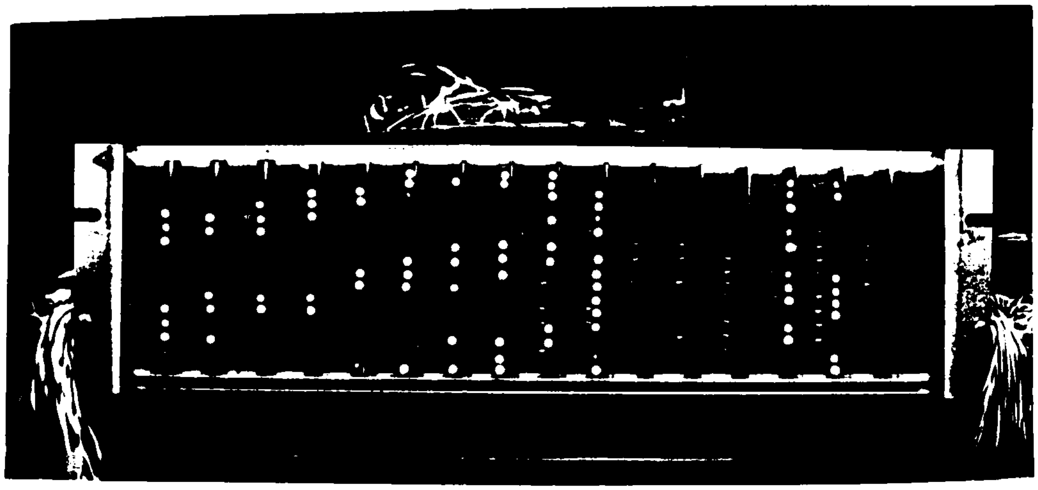


Plate XIII - Oscilloscope Display: Three Traces of Transducer

Voltage - 180 Hz

Vertical - 10 V/div

Horizontal - 5 msec/div

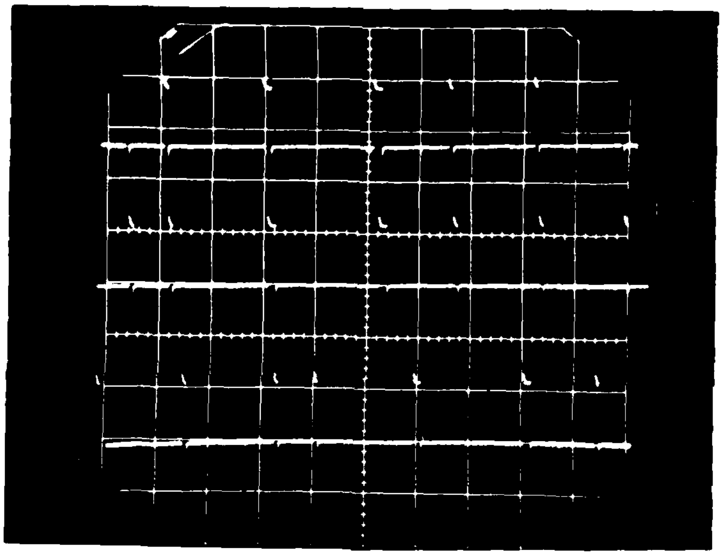


Plate XIII - Oscilloscope Display: Three Traces of Transducer

Voltage - 180 Hz

Vertical - 10 V/div

Horizontal - 5 msec/div

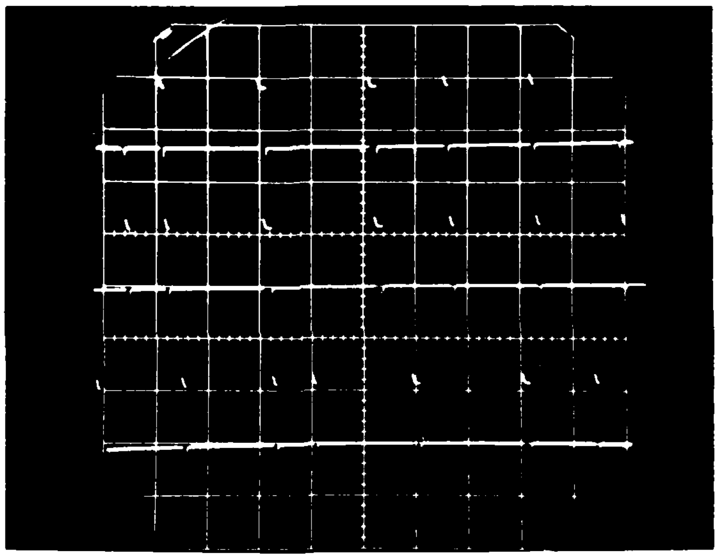


Plate XIV - Oscilloscope Display: Three Traces of Transducer

Voltage - 250 Hz

Vertical - 10 V/div

Horizontal - 5 msec/div

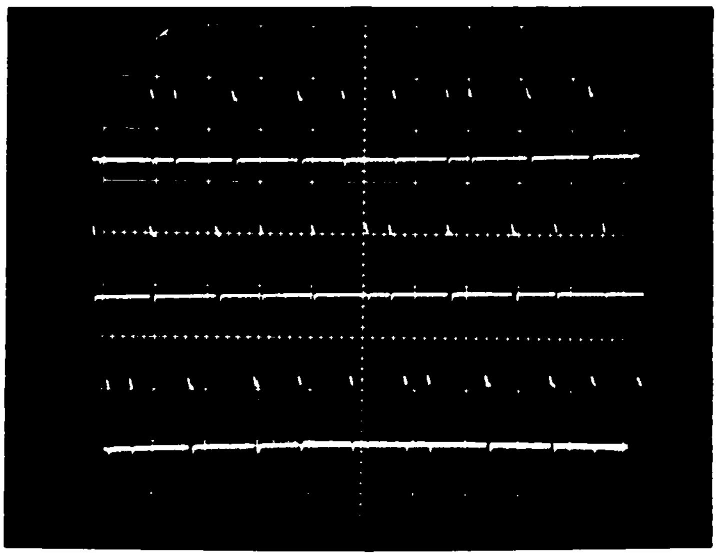


Plate XV - Oscilloscope Display: Voltages on Adjacent Transducers

Vertical - 10 V/div

Horizontal - 1 msec/div

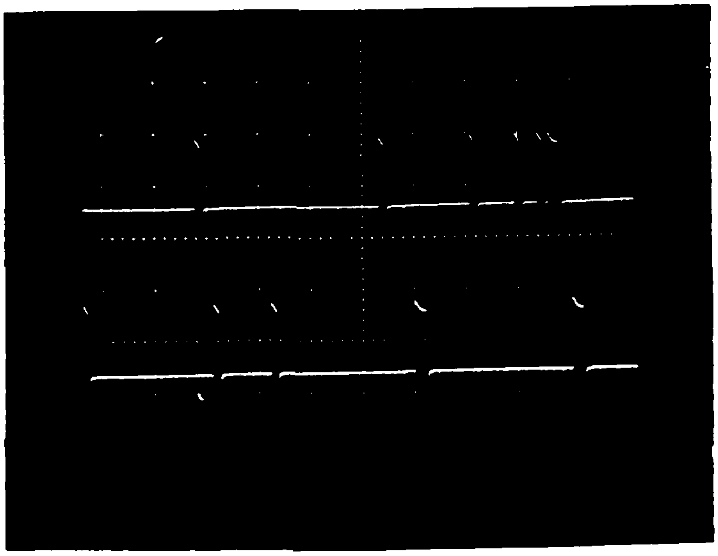


Plate XVI - Oscilloscope Display: Transducer Voltage with

Low-Frequency Gating at 5.5 Hz

Vertical - 10 V/div

Horizontal - 0.1 sec/div

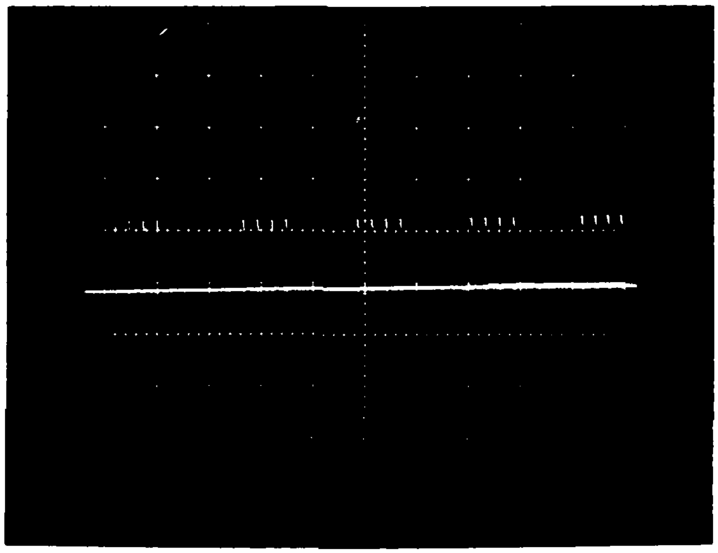


Table 3 - Transducer Current vs. Data Word Stored in RAM

Data Word	Transducer Current
0	0 mA
1	1 mA
2	16 mA
3	20 mA
4	20 mA
5	20 mA
6	20 mA
7	20 mA
8	20 mA
9	20 mA
10	23 mA
11	24 mA
12	24 mA
13	24 mA
14	25 mA
15	26 mA

CHAPTER V

CONCLUSIONS

Introduction

The test system meets all design parameters. If further experimentation reveals the selection of parameters or their ranges used for this research to be inadequate, the test system as built can be used as the basic structure of an improved version.

This chapter covers the expected use of the test system and areas in which the test system could be improved, expanded, or made more flexible.

Expected Use

The test system can be used to determine whether the parameters considered in its design are, in fact, the critical ones. Each parameter can be varied in turn, and the results compared.

By using the computer to generate patterns, controlled experiments can be done to measure the required duration of a stimulus for recognition of patterns. The frequency of vibratory stimulus can be varied to determine if the frequency for peak sensitivity is also the best frequency for recognition of patterns.

Using the camera as an image source will allow testing under conditions very similar to those which would be encountered by the

blind. Levels of contrast, stimulus duration time, and pixel conversion algorithms can be varied to determine what parameters are most important, and how to maximize the transfer of useful information.

Possible Improvements

The transducer current does not vary linearly with the value of the data word corresponding to the intensity level. An improved biasing scheme for the driver transistors should improve this.

The method of generating the random addresses could be made programmable using an additional microprocessor. This microprocessor, together with an output port, would allow the addresses which select which transducer in each column was being pulsed to be under program control. This would allow sequential scanning of individual columns or the entire array, if desired. However, to deviate from the restriction that only one transducer in any column be on at any one instant would require major hardware modification.

As built, the test system scans by columns. That is, increasing addresses used by the computer access successive locations in one column (different row elements in that column) before moving to the next column. Since many cameras (including the one used in this test system) scan by rows, future users of the test

system may wish to change this. This can be done by exchanging the lines carrying BA<0> through BA<3> with those carrying BA<4> through BA<7> on the outboard. BA<4> through BA<7> are shown in Figure 9 going to the SN74LS154, and BA<0> through BA<3> are shown in Figure 10 going to the SN74LS244, byte address buffer. Simply interchanging these two sets of four lines would accomplish this transposition.

APPENDIX A

CIRCUIT DETAILS

Introduction

This appendix describes the circuits built for this test system and shows the waveforms at key locations. The circuits are covered in the same order as in Chapter III: camera, camera interface, processing subsystem, column boards, Apple interface board, and outboard.

Camera

The camera is the Micro-D Cam from Micromint [13]. The active element is an IS-32 optic RAM. Briefly, the camera works as follows: the storage elements in the RAM are capacitors made from semiconductor material. These capacitors can be charged, discharged, or tested for level of charge (or voltage). To use the RAM as an imaging device, all the capacitors are first fully charged. The surface of the RAM is exposed to light for a predetermined time. The light falling on the capacitors causes them to discharge at a rate which depends on the intensity of the light. After the exposure time is complete, the voltage on each capacitor is measured, indicating the amount of charge left. If the charge is

below a threshold, then the light falling on that capacitor was brighter than some certain amount. If the capacitor still has more voltage than the specified threshold, then the total amount of energy in the light which fell on that capacitor was less than a given amount. By setting the exposure time and threshold, a wide range of light levels can be spatially separated. A more detailed description is given in the manual which accompanies the camera [13].

Camera Interface

The camera interface is supplied with the camera. As with the camera, circuit details are given in the manual [13]. The important fact about the camera interface is that it does the serial to parallel conversion of the camera data to allow the 6502 in the Apple //e computer to store the image easily, and provides a port which allows handshaking between the camera and the computer. The handshaking includes the computer's checking to determine if a data word is available at the interface, and the computer's sending commands to the camera to set the mode (i.e. expose or send data).

Processing Subsystem

The details of the Apple //e computer are given in the manufacturer's manual [15]. The computer accomplishes the following tasks: activation of the camera and storage of the camera's image,

processing the data which comprises the camera's image, selection of the spatial pattern to be presented by the VTA, and gating the spatial pattern presented by the VTA at a low frequency. The signals and timing required for proper interfacing will be discussed in connection with the Apple interface board, below.

Column Board

Figure 2 shows the complete wiring of the column board.

Address and data gating. Figure 3 shows the gating of the addresses to each column board and the derivation of the strobe for the CDP 1824 RAM. When SEL·N is not active (i.e. low), the board is not selected by the computer, and the random addresses RA_N are used to select memory locations, which have been loaded with values proportionate to the level of stimulation desired at the corresponding element for that column. When SEL·N is active (i.e. high), the board is selected by the computer, and BA<0> through BA<3> are gated to the address lines of the memory. Simultaneously, the data from the computer data bus is gated onto the data lines of the memory by the 80C95 shown in Figure 2, and the BI/OSEL, ANDed with SEL·N, strobes the data into the memory. The address, which is RA_N except for the half microsecond during which the computer is writing to the RAM on the column card, is also sent to the 4067B sixteen channel analog multiplexer, as shown in Figure 3.

Digital to analog conversion. Figure 4 shows the digital to analog conversion and multiplexing circuitry. The data output of the RAM is connected to the input of the digital to analog converter IC (DAC 0808). This produces an analog output which is connected to the input of an LM 1458 operational amplifier. The addresses which are used to select which data word is read from the RAM are also sent to the 4067B analog multiplexer, as shown in Figure 3. This causes the input of the multiplexer to be connected to the output specified by the signals on the multiplexer's address lines A through D. These 16 outputs are each connected to the input of an operational amplifier, whose output is then connected to one of the 16 driving transistors. In this way, the digital data word which is selected by the random address is converted to analog and routed to the correct driving transistor and, therefore, the correct transducer in the VTA.

Apple Interface Board

Figure 5 shows the Apple interface board which is used to output data, address and timing to the external circuitry. The two SN74LS154s decode the high-order byte of the address bus, causing BSEL' to go low when a WRITE to $C2XX is performed. I/OSEL is buffered using the SN74LS02 as an inverter, producing BI/OSEL, which goes high during Φ1 of the Apple clock when slot 2 is addressed (see Figure 6, 6502 timing signals [13]). This signal is used to

strobe the data into the RAMs on the column boards. The low-order byte of the address bus and the entire eight bits of the data bus are buffered with SN74LS244s. Figure 7, Apple Interface Board Wiring Diagram, is included for ease of component location. All these signals are passed to the outboard via a 26-pin connector and ribbon cable.

Outboard

Column select logic. Figure 8 shows the column select logic on the outboard. (Figure 9 is the column select wiring diagram showing component location.) Bits 4-7 are decoded by the SN74LS154 to produce sixteen COLN' lines which are ANDed with BSEL' to produce BSEL·N. This signal is used to gate the data from the computer (BD<0> through BD<3>) and the low-order nibble of the address (BA<0> through BA<3>) to the RAM on the column boards. The address and data lines are double buffered, that is, each signal is fed to two buffer amplifiers. The outputs of the buffer amplifiers each drive eight of the sixteen column cards. This is needed because the fan-out on LS TTL is only ten (each output can drive only ten inputs), and there are sixteen inputs which must be driven. This double buffering is done by two SN74LS244s on the outboard (see Figure 10).

Random address generation. The outboard also produces the random addresses needed for uncorrelated stimulation. Figure 11,

Random Address Generation Logic Diagram on Outboard, shows the circuit for this. The NE-555 oscillator provides the system clock, and drives the SN74164 shift register. The outputs, Q_A through Q_H, are buffered by an SN74LS244, and thence distributed to the column boards in groups of four. The feedback path for the pseudo-random noise generator uses taps one and seven, exclusive-or'ed by the SN7486. In case the initial state of the shift register happens to be all zeros upon power-up, the two additional exclusive-or gates are used to invert the feedback for approximately ten seconds, until the 470 μF capacitor charges sufficiently to present a logic one to the gate at pin five of the SN7486. When a logic one is sensed, the gates no longer invert the feedback signal, and normal pseudo-random code is generated. These address, data and timing signals are then sent to the sixteen column boards arranged vertically in a card cage.

PARTS LIST

General

1	Apple //e computer w/64K	
1	Apple Monochrome Monitor	
1	Disk Drive	
1	Micro-D Cam with interface	

Apple Interface Board

2	SN74LS154	4 to 16 line decoder
2	SN74LS244	8 line tri-state buffer
1	SN74LS02	Quad 2-input NOR gate
1	Apple prototype board	
5	0.1μF 50V capacitor	

Outboard

1	SN74LS154	4 to 16 line decoder
4	SN74LS02	Quad 2-input NOR gate
1	SN74LS04	Hex inverter
3	SN74LS244	8 line tri-state buffer
1	NE-555	timer
1	SN74164	shift register
1	SN7486	Quad 2-input XOR gate
1	5K ohm variable resistor	
1	0.22μF capacitor	
1	0.15μF capacitor	
1	470μF capacitor	
1	3K ohm resistor	
1	12K ohm resistor	

Column Board (each board - 16 required)

1	4067B	16-channel analog multiplexer
1	CDP1824	32 by 8 bit static RAM
1	DAC0808	digital to analog converter
1	SN74LS244	8 line tri-state gate
1	80C95	Hex non-inverting CMOS gate
1	SN74LS00	Quad 2-input NAND gate
9	1458	Dual operational amplifier

<u>Column Board - Continued</u>

16	2N2906	PNP transistor
16	LED red	
16	2.2K ohm resistor	
16	200 ohm resistor	
1	2.7K ohm resistor	
1	1K ohm resistor	
2	5K ohm resistor	
1	6.8K ohm resistor	
5	0.1μF capacitor	
1	custom printed circuit board	

<u>Card Cage</u>

1	16-position card cage with 16 44-pin card sockets

Definitions of Terms

AND - indicates the coincidence of two signals. Indicated by a · between the signal names.

BI/OSEL - buffered input-output select. The I/OSEL signal is generated by the Apple //e computer and is active (high) during Φ 1 of the clock when expansion slot #2 is addressed.

Bit - binary digit. Either a 1 or a 0. The data present on one digital line at any one instant.

Byte - eight bits which are taken together as an entity. For example, the signals on the data bus comprise a byte. The signals on the address bus consist of two bytes.

CMOS - complementary metal oxide semiconductor. A family of integrated circuits which use low power and operate at moderate speed (up to a few Megahertz).

Fan-out - the number of inputs to gates that a single output from a gate is capable of driving. With LS TTL, this is limited to ten, so one output can drive a maximum of ten inputs.

Gating - selective passing or blocking of signals. The signals may be data or address.

Nibble - half a byte. Each byte of the address bus consists of two nibbles - a high-order nibble (the four most significant digits) and a low-order nibble (the four least significant digits).

NOT - reversal of activity level. Indicated by ' after signal name in text or by overbar in diagrams. This indicates that a signal is active (or true) when the voltage is low.

RA_N - one of the random addresses presented to the column board. The random nature of the addresses provided to the column board causes the signals which drive the transducers of the VTA to be temporally uncorrelated.

SEL·N - select AND N. The coincidence of SEL, which indicates the presence of the $C2 on the high-order byte of the address bus, and N, which indicates the presence of N on the high-order nibble of the low-order byte of the address bus.

Strobe - a pulse which causes a memory device to accept the data present on its data lines and store it at the address indicated by the signals on its address lines.

TTL - transistor-transistor logic. A family of integrated circuits characterized by low cost, wide availability, and moderate speed (up to a few Megahertz).

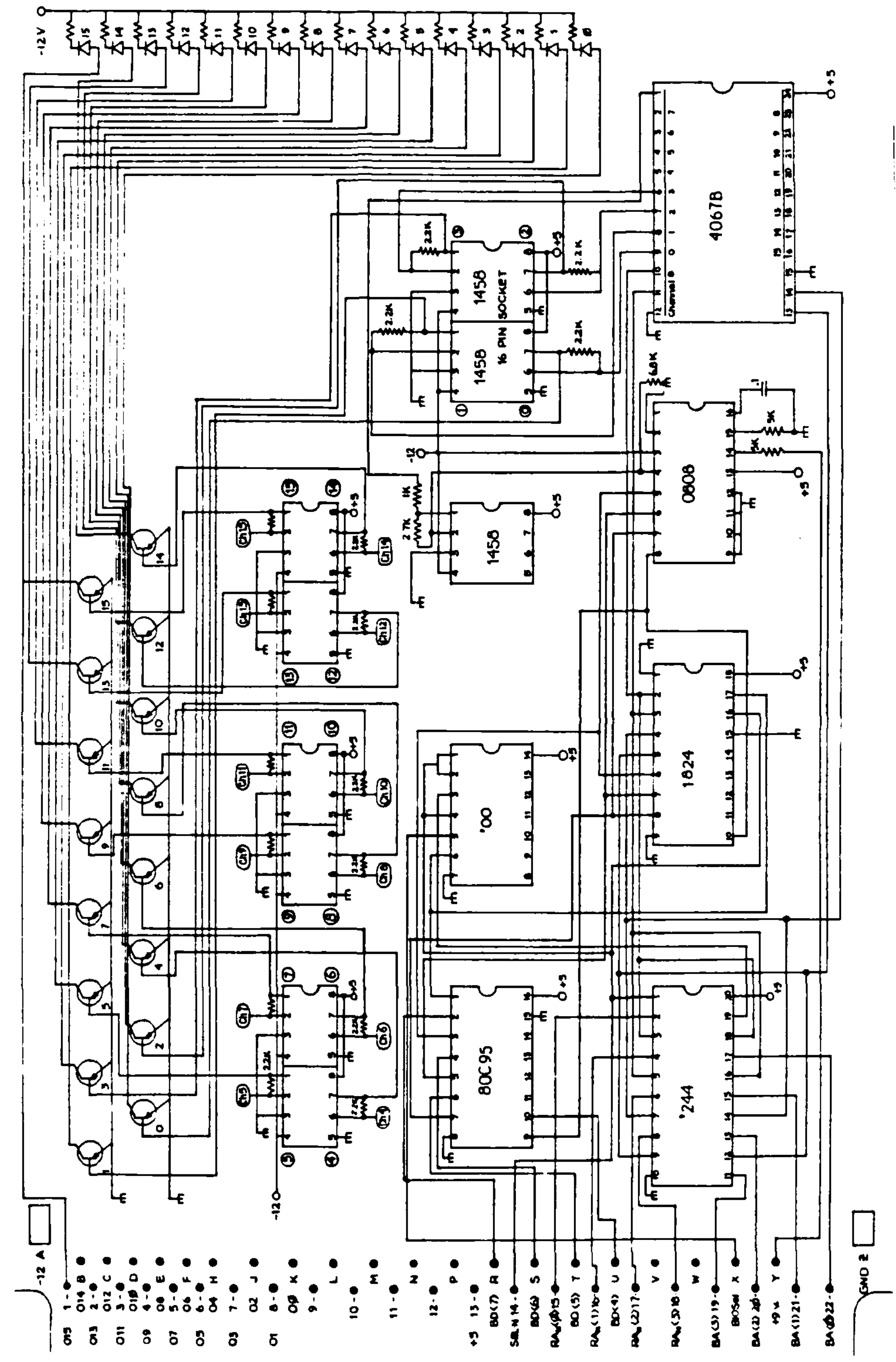


Figure 2 - Column Board Wiring Diagram

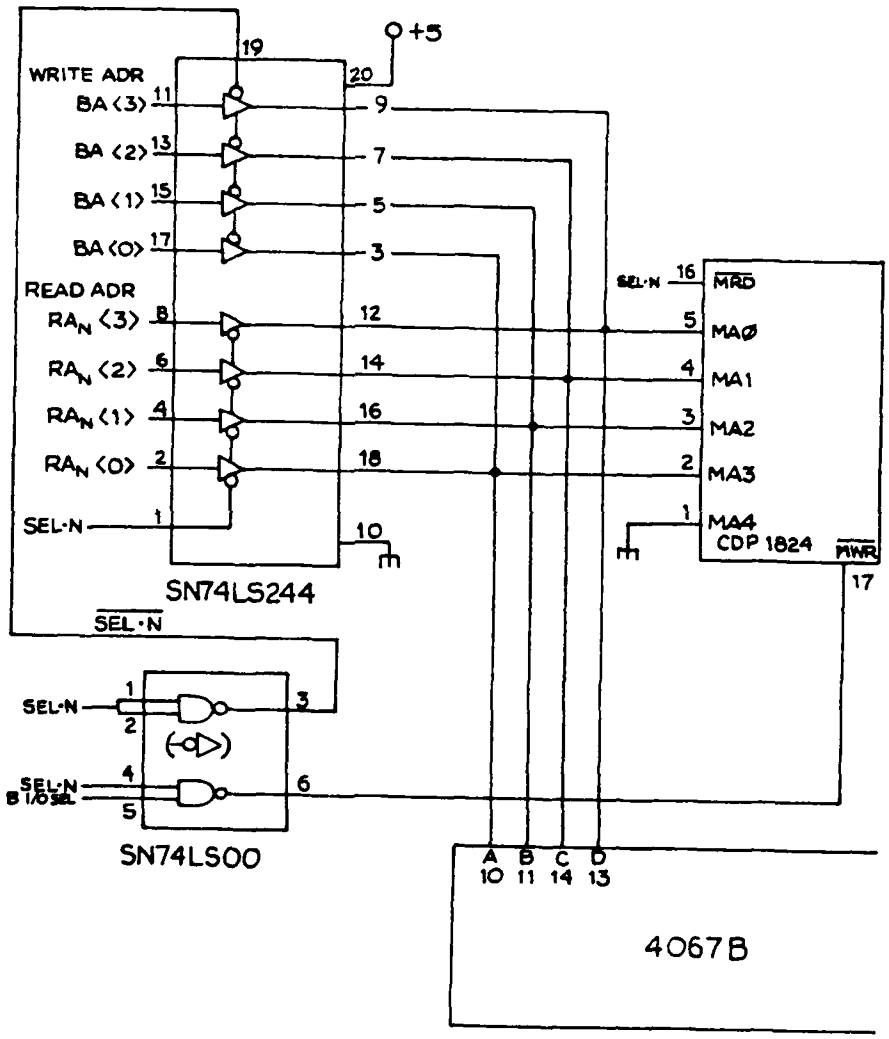
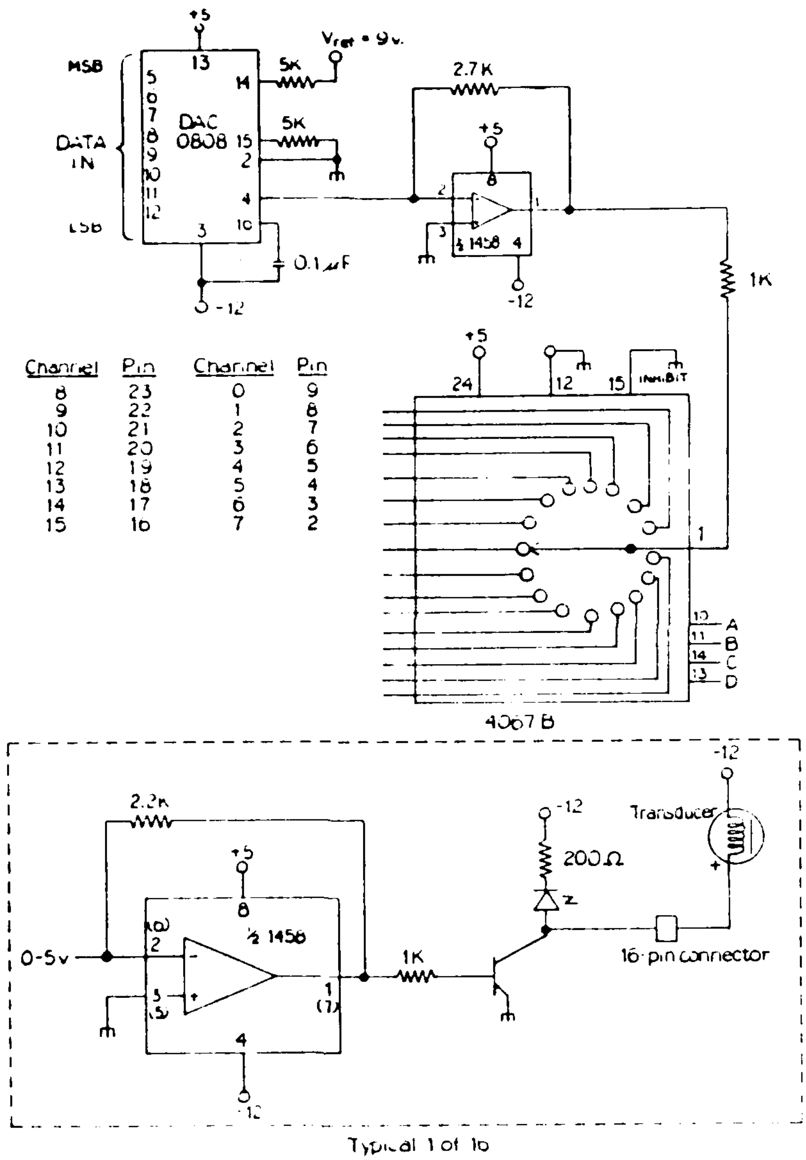


Figure 3 - Address Gating on Column Board



Channel	Pin	Channel	Pin
8	23	0	9
9	22	1	8
10	21	2	7
11	20	3	6
12	19	4	5
13	18	5	4
14	17	6	3
15	16	7	2

Figure 4 - Digital to Analog Conversion on Column Board

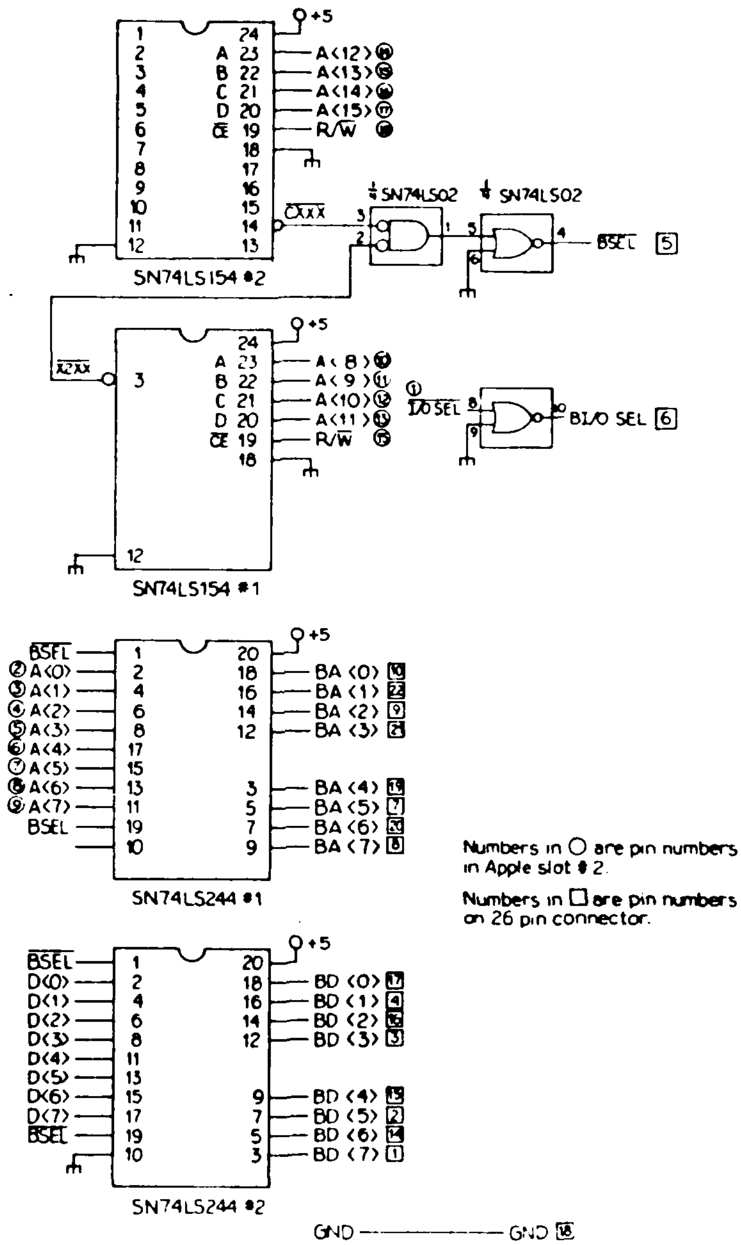


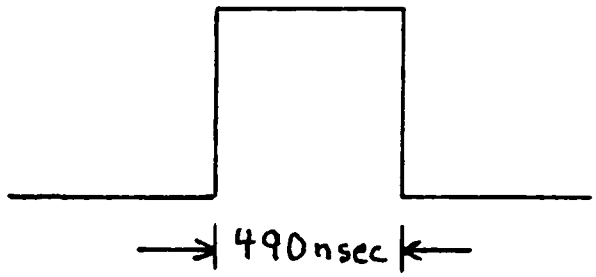
Figure 5 - Apple Interface Board Logic Diagram

Figure 5 (continued)

BI/OSEL on

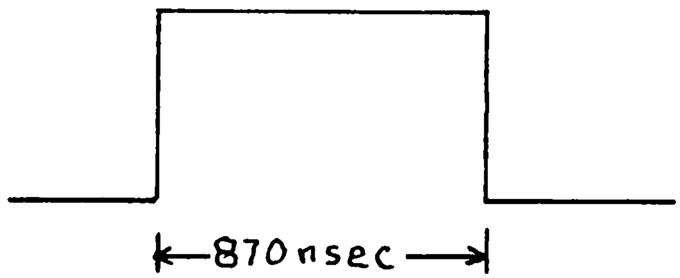
Apple Interface

Board



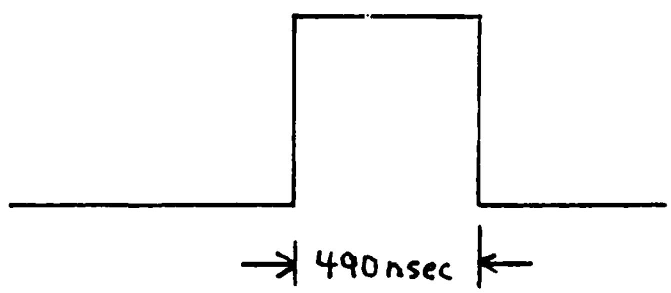
BSEL·N on

Outboard



BI/OSEL·BSEL·N on

Column Board



All signals 5V in amplitude

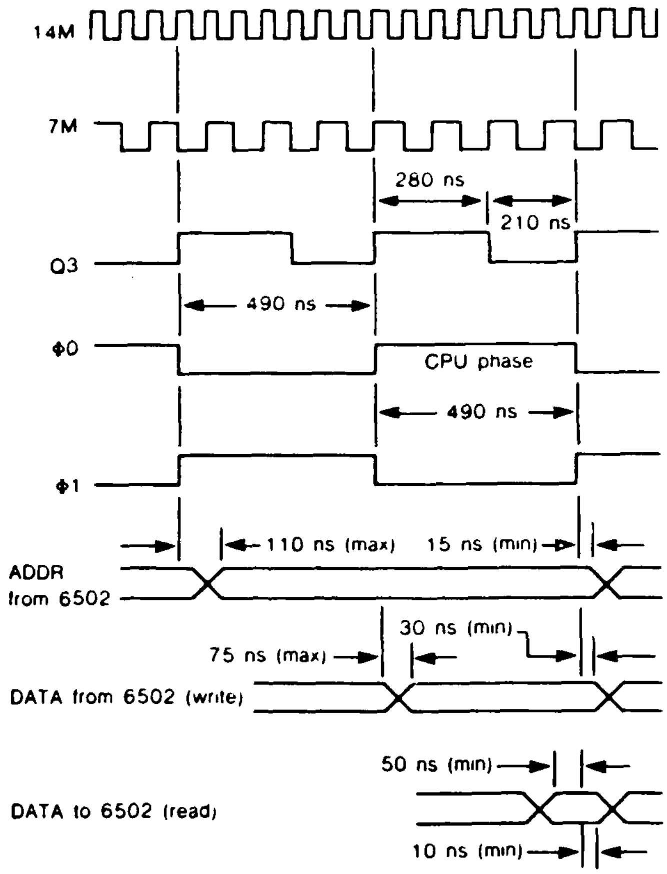


Figure 6 - Apple Computer: Timing Diagram

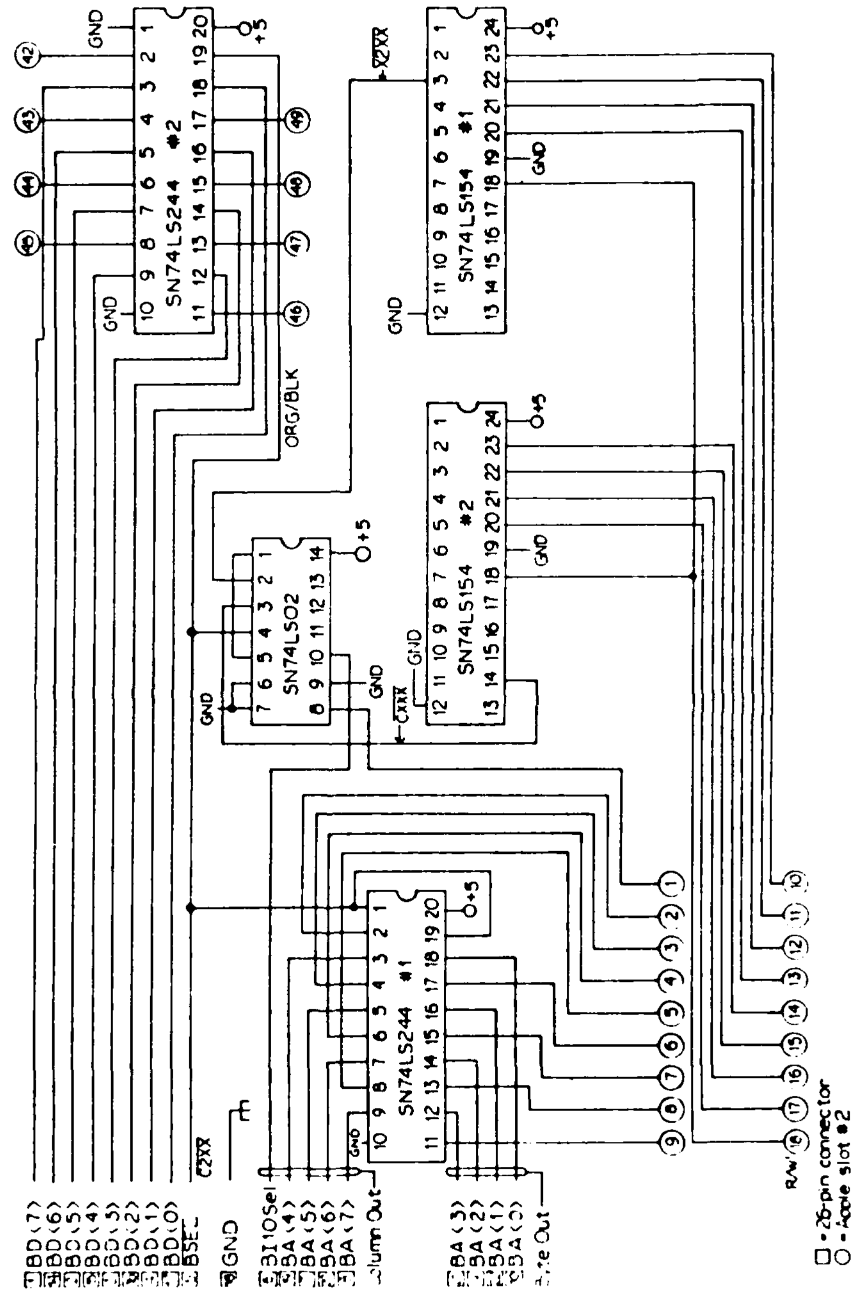
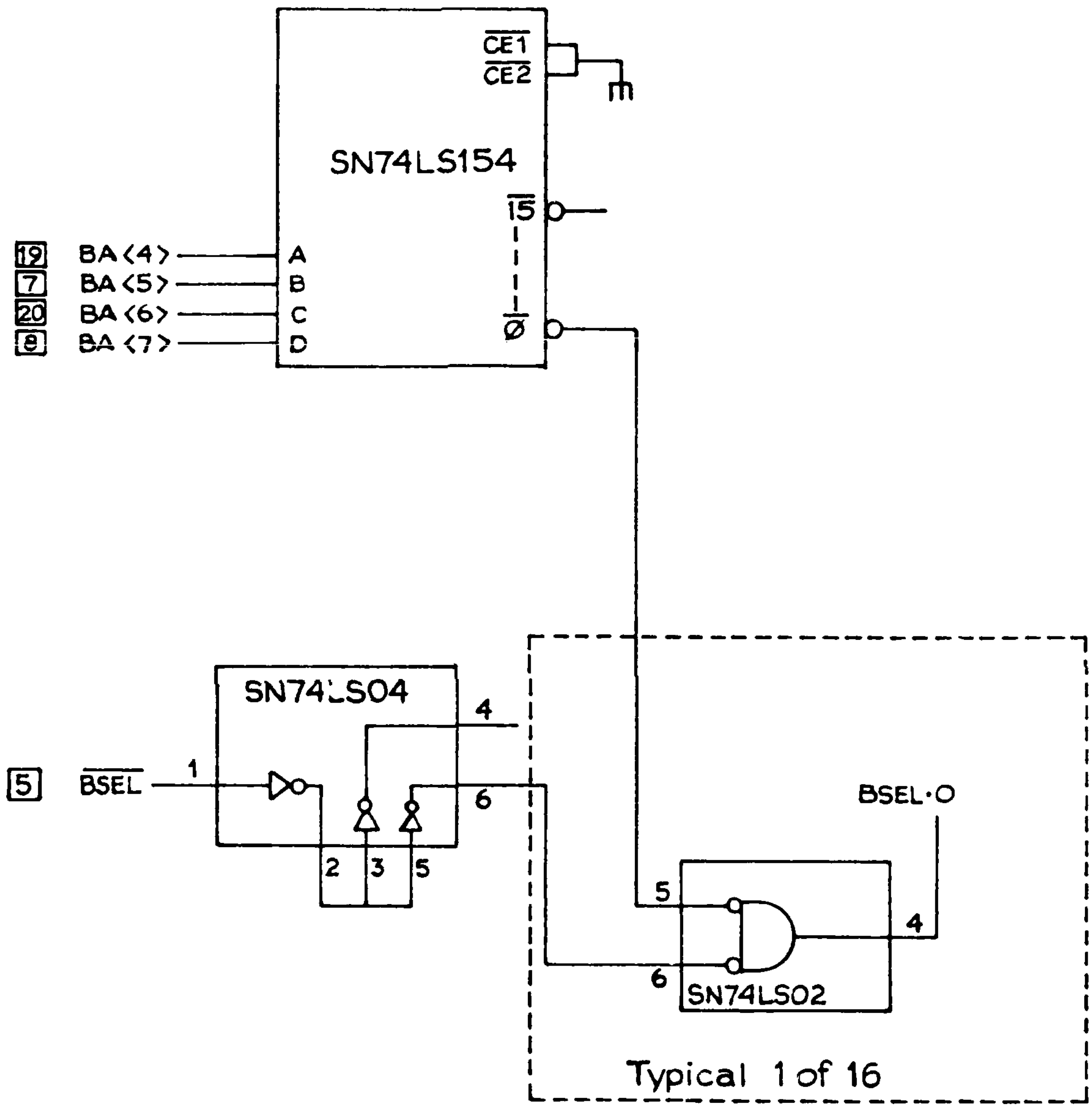


Figure 7 - Apple Interface Board: Wiring Diagram



□ = 26 pin connector

Figure 8 - Column Select Logic on Outboard

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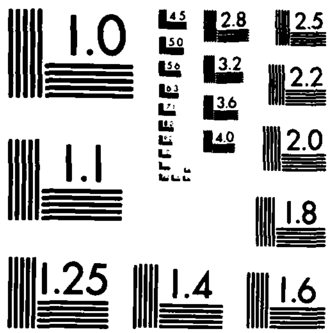


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

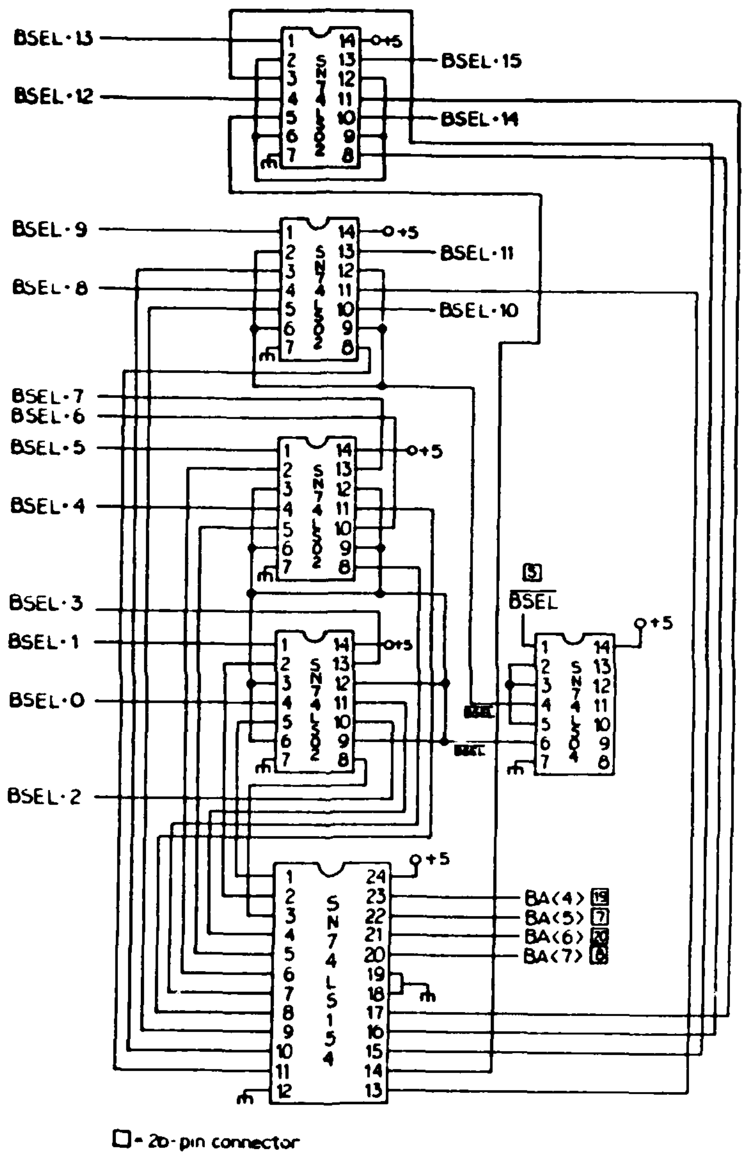
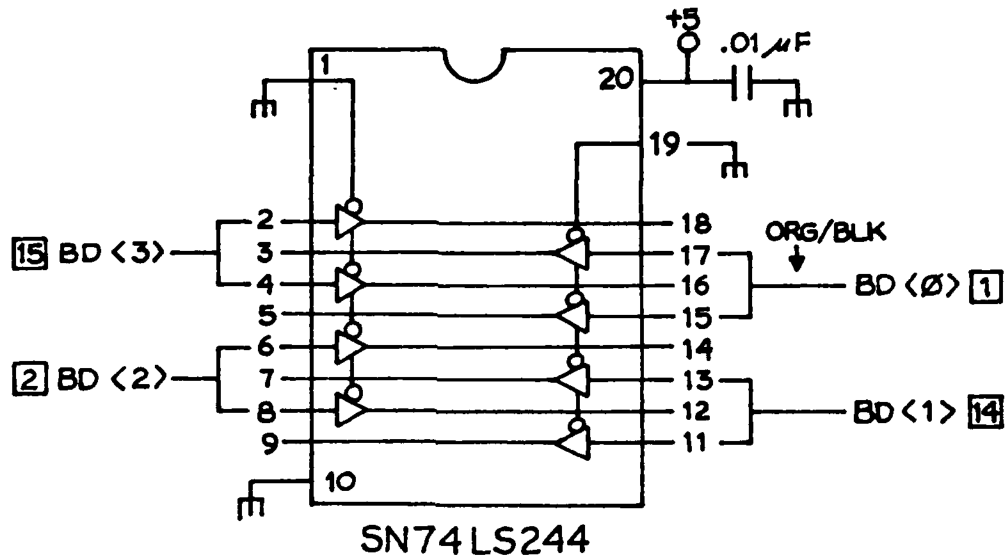


Figure 9 - Column Select Wiring Diagram on Outboard

Data Buffer (to write)



Byte Address Buffer (To write)

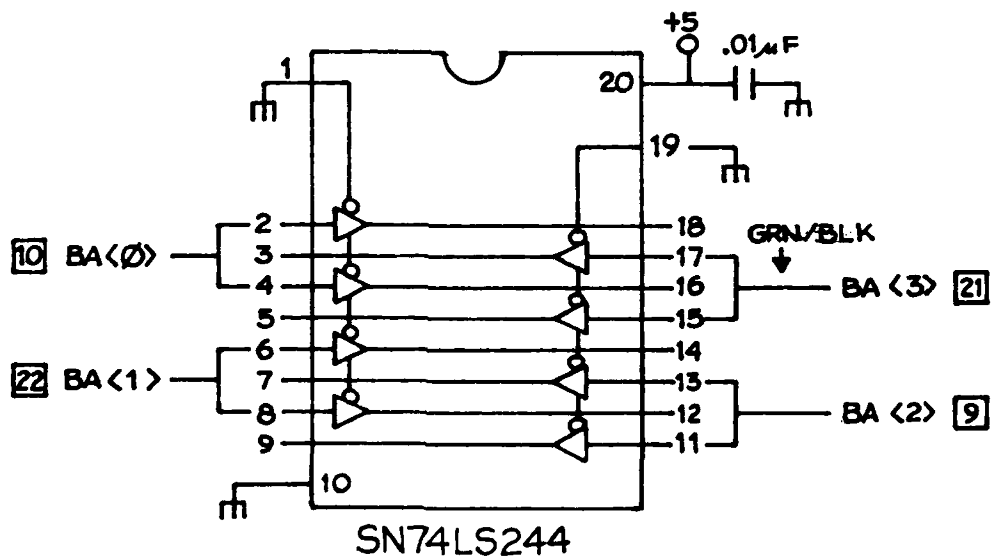


Figure 10 - Address and Data Buffering on Outboard

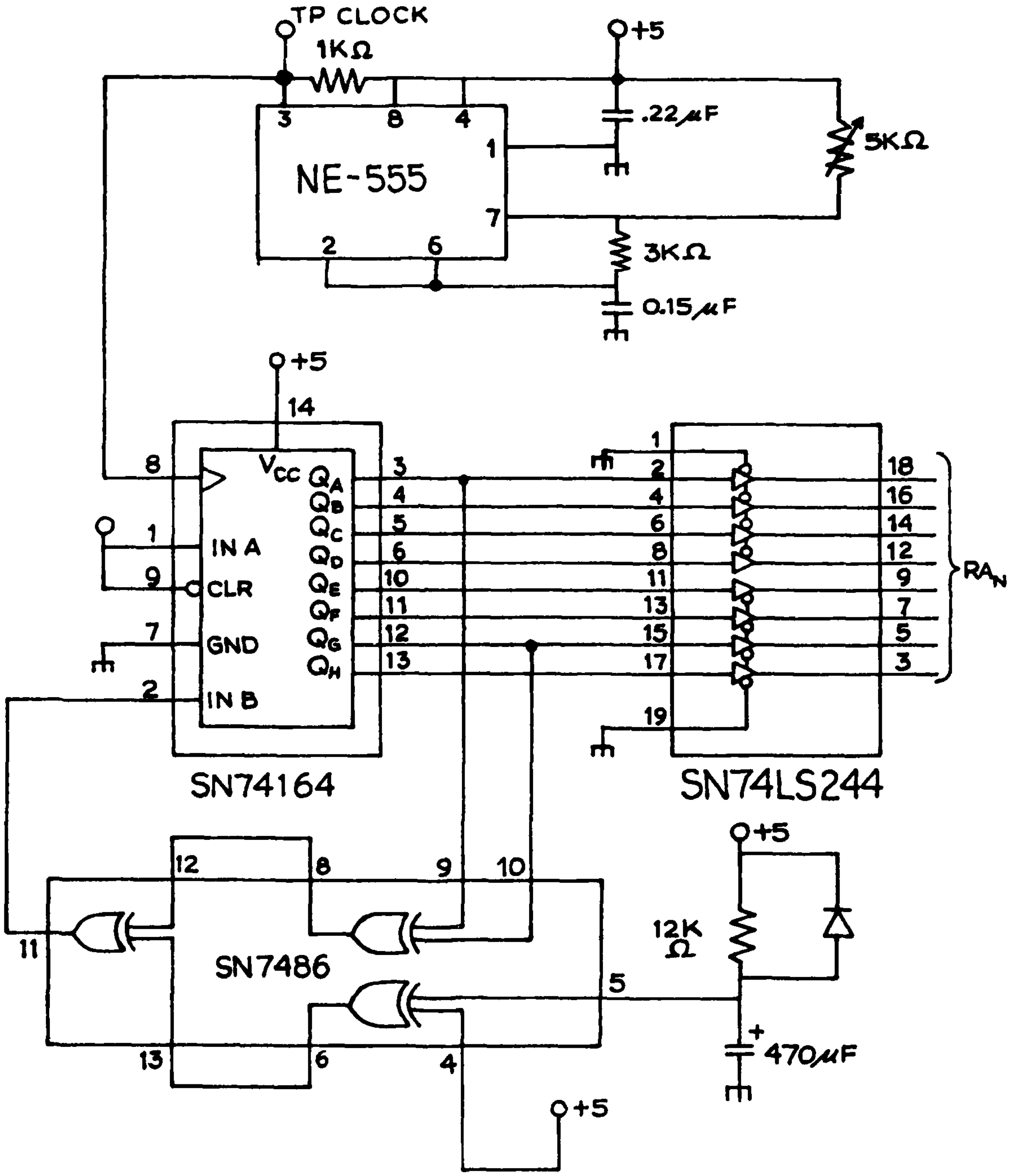


Figure 11 - Random Address Generation Logic on Outboard

REFERENCES

[1] Berne, R. M., and Levy, M. N., Physiology, C. V. Mosby Co., 1983.

[2] Geldard, F. A., "Some Neglected Possibilities of Communication", Science, 135, pp. 1583-1588, 1960.

[3] Bach-y-Rita, P., "Sensory Plasticity: Applications to a Vision Substitution System", Acta Neurologica Scandinavia, 43, pp. 417-426, 1967.

[4] White, B. W., Saunders, F. A., et al. "Seeing with the Skin", Perception and Psychophysics, 7, pp. 23-27, 1970.

[5] Saunders, F. A., and Collins, C. C., "Electrical Stimulation of the Sense of Touch", Journal of Biomedical Systems, 2, pp. 27-37, 1971.

[6] Szeto, A. and Saunders, F. A., "Electrocutaneous Stimulation for Sensory Communication in Rehabilitation Engineering", IEEE Transactions on Biomedical Engineering, 29, pp. 300-308, 1982.

[7] Saunders, F. A., "Information Transmission across the Skin: High-Resolution Tactile Sensory Aids for the Deaf and Blind", J. Neuroscience, Vol. 19, pp. 21-28, 1983.

[8] Rogers, C. H., "Choice of Stimulator Frequency for Tactile Arrays", IEEE Transactions on Man-Machine Systems, Vol. MMS-11, No. 1, pp. 5-11, 1970.

[9] Kovach, Mark, "Design Considerations for the Construction of a Vibrotactile Array", (unpublished Master's Thesis, Bio-Medical Engineering Program, The Ohio State University), 1985.

[10] Mountcastle, V. B., Medical Physiology, Vol. 2, pp. 348-388, C. V. Mosby, Co., 1974.

[11] Wilska, A., "On the Vibrational Sensitivity in Different Regions of the Body Surface", Acta. Physiol. Scand., Vol. 31, 1954.

[12] Weinstein, S. "Intensive and Extensive Aspects of Tactile Sensitivity as a Function of Body Part, Sex, and Laterality", The Skin Senses , Kenshalo, (Ed.) pp. 195-218, Springfield: Charles Thomas, 1968.

[13] Micro D-CAM Apple Version , The Micromint, Inc., 516 Willow Avenue, Cedarhurst, NY 11516, 1983.

[14] Ciarcia, S. A., "Build the Micro D-Cam Solid-State Video Camera", Byte, pp. 67-86, October 1983.

[15] Apple// Reference Manual , Apple Computer, 20525 Mariani Avenue, Cupertino, CA 95014, 1982.

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